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ENVIRONMENTAL STRESS SCREENING

Hughes Aircraft Company

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Procedures for planning, monitoring and controlling Environmental Stress Screening programs were developed. The technique requires estimation of the number of part and workmanship defects introduced in manufacture, the effectiveness of stress screens in precipitating defects to failures, and the failure rate of defects under particular stress environments. A draft MIL-STD, prepared as part of the study, is included in the report. The data and analysis methods used in deriving the MIL-STD data tables are discussed and illustrative examples of the use of the MIL-STD procedures are also contained in the report.

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FOREWORD

With increasing use of stress screening as a means to precipitate defective parts and workmanship defects arises the need for a better understanding of its costs and benefits to permit a systematic approach to planning, monitoring and controlling the stress screening process that will benefit the manufacturer and user alike.

The data base needed for the systematic approach (data for initial defect estimation, stress screening effectiveness, and defect precipitation rates) is undeveloped at this time and there do not appear to be any major efforts underway for its development. It is the belief of the developers of the quantitative approach to stress screening that imposition of that methodology on military equipment manufacturers by Government procuring activities will foster the development of the required data base and will result in more effective stress screening techniques which will have significant impact on the quality and reliability of products delivered to the Government.

A draft military standard developed in this study includes methods for estimating the number of defects initially present, for estimating the effectiveness of stress screens and for deriving a failure free time interval which is related to the probability of a product being free of defects on delivery. These methods were developed empirically from scant data and are not considered generally applicable to all product types. They are included in the military standard to serve as an aid to the manufacturer, to be used during product development and early production to provide some expectations of screening fallout. Actual fallout when compared to expected fallout permits adjustments to initial defect and screening effectiveness estimates, resulting in a quantitative model tailored to each manufacturer's products that can then be used for cost-effective tailoring of stress screens for subsequent production.

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1.0 INTRODUCTION AND SUMMARY

1.1 Introduction. Environmental Stress Screening is now being employed throughout the defense industry as a means of precipitating latent part and workmanship defects prior to fielding, with the expectation that improved field reliability and reduced support costs will result. The types of stress screens employed are based on published guidelines (e.g., NAVMAT P-9492) and generally consist of temperature cycling and/or random vibration. Other stress screens such as high temperature burn-in, cold soak, and power on-off cycling are also employed. Stress screens are applied with the understanding that if latent defects are present, the stress screen will precipitate them and no defects will remain upon completion of the stress screens. It is more likely that a variety of part and workmanship defects exist, particularly in development and early production equipment, and that stress screening will eliminate most, but not all defects. The ability of stress screens to precipitate the defects varies with defect type and screening stress and time parameters. There is currently no methodology for predicting the results of and evaluating the effectiveness of stress screens and therefore, it is not possible to determine the cost effectiveness of existing or proposed screens.

1.2 Objectives and Scope of Study. The objective of this study was to develop a quantitative technique for planning, monitoring and controlling the cost effectiveness of stress screening programs for electronic equipment and to prepare a draft military standard based on the developed technique. The study addressed the four questions shown in Figure 1.1. Latent defects are introduced in equipment through defective parts and deficiencies in the manufacturing assembly process. Design related defects, though not insignificant, are not considered in the techniques developed. Stress screens act on part and workmanship defects with resulting fallout, but since screens are less than 100% effective, some defects escape in fielded equipment. A method for estimating the number of defects initially present was developed and is described later.

The effectiveness of stress screens is measured by test strength determined from screening strength equations developed in a previous study[1] and updated in this study based on actual screening results and test detection efficiency. The question of what is a reasonable number of defects to escape is addressed based on equipment complexity and a tradeoff of stress screening cost and resulting field reliability. A method for establishing the allowable number of defects remaining in a delivered product is provided.

1.3 Summary of Quantitative Technique. An overview of the quantitative technique developed is provided below with details for each step provided in Section 2 of this report. Three inputs are required from the procuring activity (PA), viz., Mean Time Between Failure (MTBF), Yield, and Cost Threshold. The MTBF is the specified value (upper test value) for the equipment being procured. Yield is defined as the probability that the equipment being procured is free of defects. The Cost Threshold is the average cost per field repair.

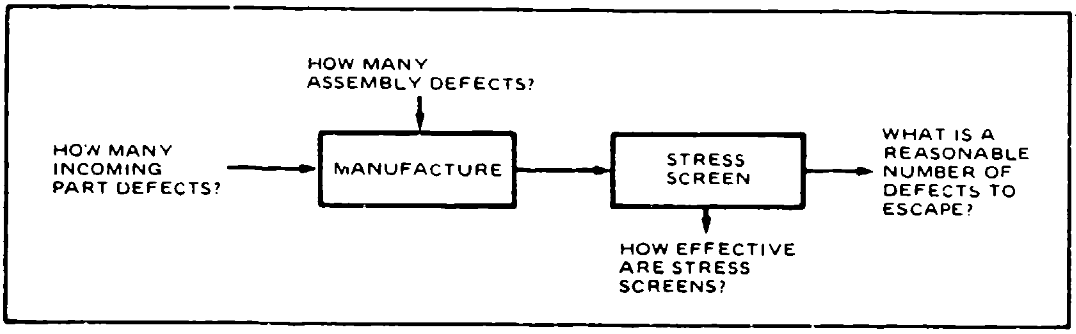

Figure 1.1. The Qua..ı'ative Problem

The contractor then performs the following steps, shown on Figure 1.2:

1. Estimate the number of defects entering each equipment during the manufacturing process.

2. Determine the number of defects (D) that can escape the stress screen(s) and meet the Yield requirement.

3. Determine the required test strength to precipitate the number of defects corresponding to D.

4. Select the appropriate stress screen(s) that provide the required screening strength.

5. Determine the required failure-free period to demonstrate the specified Yield.

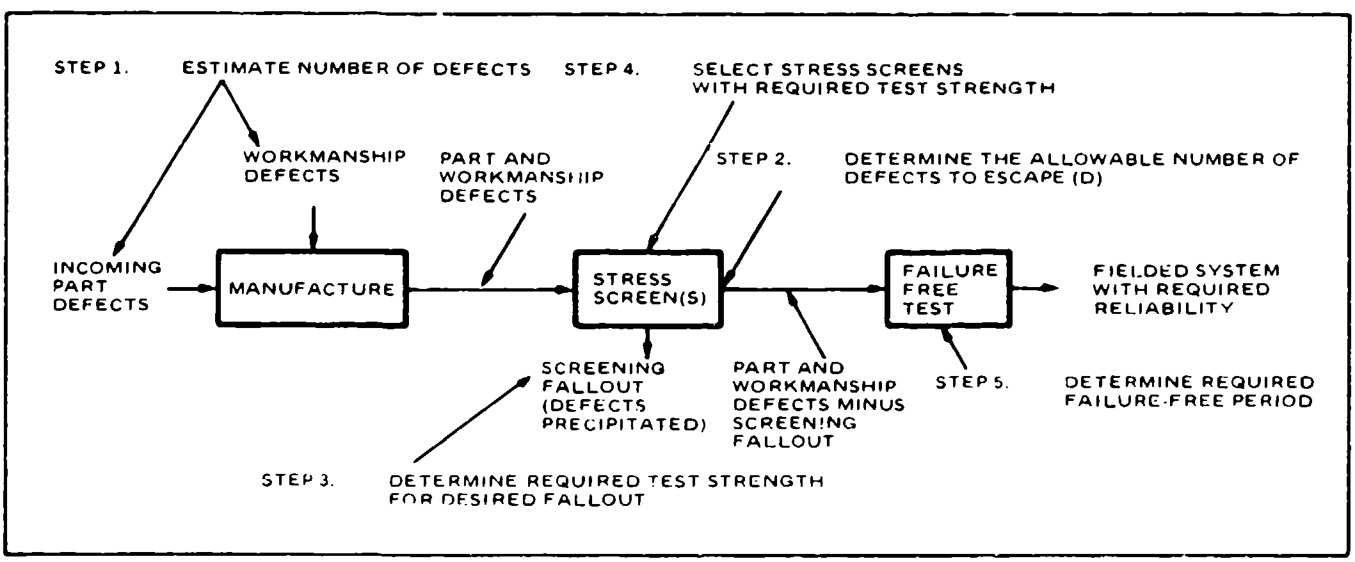

Figure 1.2. Summary of the Quantitative Stress Screening Technique

2.0 STUDY DETAILS

2.1 <u>Study Approach</u>. The concept of test strength (screening strength x probability of detection) was developed on a previous study[1] and equations were provided for estimating screening strength based on stress levels and time. Screening strength is a measure of the ability of a stress screen to transform incipient defects into detectable failures. Having only a measure of screening strength is not sufficient because the number of defects escaping in delivered equipment (and resulting in early field failures) is also of importance. Therefore, the total number of defects introduced in manufacture of an item must be considered. Figure 2.1 shows the inter-relationships among incoming defects, test strength, screening fallout, and escaping defects.

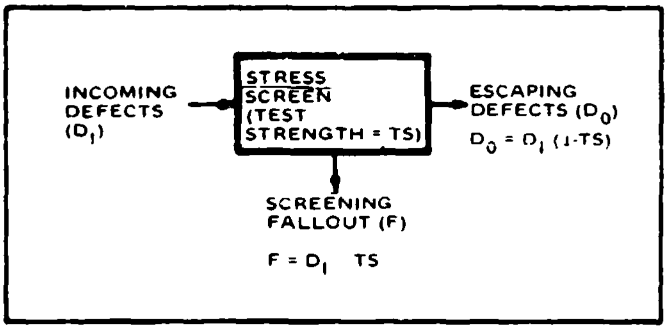

Figure 2.1. Stress Screening Variables

If the test strength (TS) is known precisely, the number of incoming and escaping defects can be determined exactly from the screening fallout (F) by,

$$D_I = F/TS$$

and

$$D_O = D_I - F$$

The disadvantage of using only test strength is that the number of escaping defects is known <u>after</u> screening fallout is measured, which, if large, is unacceptably late.

In this study, a technique was developed for estimating the number of defects present in equipment before stress screening. Initial defect estimates used with test strength estimates provide planning estimates of screening fallout and escaping defects. The escaping defects estimate is necessary to determine if the planned screens will provide the desired field MTBF (MTBF vs escaping defects is described in para. 2.2.6). If it is projected that the desired MTBF will not be achieved, either the test strengths must be increased or the number of initial defects decreased. The planning estimate for screening fallout is useful in stress screen evaluation by comparison of actual versus estimated fallout.

2.2 Estimating the Number of Defects Initially Present.

2.2.1 General. Stress screening is intended to precipitate part and workmanship defects. The number and type of part defects present are dependent on part physical construction, materials and processes used in fabrication and testing, the manufacturer's internal screening, and the degree of protection afforded in handling, transportation and storage. These factors also account for predicted part random failure rates. Therefore, it is expected that there is a correlation between random failure rates and initial fraction defective for each part type. If a data set were available for initial fraction defective for a given part type, quality level and use conditions, that data could be extrapolated for all other quality levels and use conditions of that part type using the models in MIL-HDBK-217.[2]

Latent workmanship defects (or more generally, manufacturing process defects) that result in early electronic equipment failures are primarily associated with electrical connections (e.g., solder joints, crimp connections, coax connectors, PWB interconnections, mechanically secured terminals, and connector mating surfaces). There is also expected to be a correlation between initial connection defects and predicted connection random failure rates, allowing the use of MIL-HDBK-217 as a guide for defect estimation.

2.2.2 Data Source. There is no published historical data from which initial fraction defective estimates can be derived. One data source[3] exists which provides limited data on factory defect rates and field failure rates for parts of various quality grades. See Table 2.1. This data set was used to derive the initial part fractions defective for several part types. The fraction defective is derived by summing the total number of defects detected in the factory and field and dividing by the total part quantity. This method may result in a slightly larger than actual fraction defective because some of the field failures may have been random failures rather than precipitated defects. A balancing factor, however, is that some defects may have remained undetected in the fielded equipment at the time that the data was assembled. A high estimate of fraction defective is an error on the correct side, requiring more, rather than less, stress screening to achieve a desired field reliability.

TABLE 2.1 FACTORY AND FIELD FAILURE DATA FOR VARIOUS PART TYPES[3].

Part Type	Quality Grade	Quantity	Factory Defect Rate (per 10^6)	Field Part Hours (10^6)	Field Failure Rate (10^{-6})	Field Defect Rate* (per 10^6)
Microelectronic Devices	C-1	624,087	160	8,580	0.025	343
Transistors	JAN	107,398	60	1,536	0.020	286
Diodes	JAN	206,133	50	1,861	0.004	36
Capacitors	ER-M	1,292,967	32	1,735	0.022	30

*Ground, Fixed Environment

2.2.3 Determining Initial Fraction Defective from Data Set. The data set in Table 2.1 has the following known characteristics:

- Microelectronic Devices are Quality Grade C-1
- Transistors and Diodes are Quality Grade JAN
- Capacitors are Quality Grade ER-M
- Field Data was collected from Ground Base Operation

The following assumptions were made:

- Ground Based Operation corresponds to the Ground, Fixed Environment of MIL-HDBK-217
- Factory Operation also corresponds to a Ground, Fixed Environment
- All Failures Recorded are Precipitated Defects.

The fractions defective for transistors, diodes and capacitors were computed as follows:

$$\text{Fraction Defective} = \text{Factory Defect Rate} + \frac{\text{Field Failure Rate} \times \text{Field Part Hours}}{\text{Part Type Quantity}}$$

The following fractions defective were calculated.

Transistors,	60 + 286	=	346 defects/10^6
Diodes,	50 + 36	=	86 defects/10^6
Capacitors,	32 + 30	=	62 defects/10^6

Since the quality grades of the part types in the data set were known, extrapolation of the fractions defective to other quality grades was made by using the quality factors (π_Q) of MIL-HDBK-217, as shown in the following example for transistors:

$$\text{Fraction Defective} = \frac{\pi_Q\,(\text{JANTX})}{\pi_Q\,(\text{JAN})} \times \text{Fraction Defective (JAN)}$$

$$= \frac{0.24}{1.2} \times 346 \times 10^{-6}$$

$$= 69.2 \times 10^{-6}$$

This value is shown in Table 2.4 in the G_F environment row and the JANTX quality level column. To determine the fraction defective for other application environments, the <u>field</u> fraction defection portion of the <u>total</u> fraction defective is adjusted by the environmental factor (π_E) of MIL-HDBK-217 while the <u>factory</u> fraction defective portion remains as a fixed G_F environment. For example, the fraction defective for a JAN quality level transistor for (Group I) in a G_M environment is,

$$= (60 + 286 \times \frac{18}{5.8}) \times 10^{-6}$$

$$= 948 \times 10^{-6}$$

This methodology was used for Tables 2.4, 2.5, and 2.7.

The general calculation for fraction defective of any part type (except microelectronic devices) of any quality factor used in any application environment is:

$$\text{Fraction Defective} = \frac{\Pi_{Q1}}{\Pi_{Q2}} \left[(FFD) \frac{\Pi_{E1}}{\Pi_{GF}} + FDR \right]$$

where Π_{Q1} is the quality factor for which the fraction defective is being calculated

Π_{Q2} is the quality factor in the data set.

FFD is the field fraction defective

Π_{E1} is the applications environment factor for which the fraction defective is being calculated

FDR is the factory defect rate (Table 2.1)

The fractions defective for microelectronic devices are determined in a slightly different way because the form of the failure rate model in MIL-HDBK-217 does not have the application environment factor, Π_E, as a direct multiplier.

The microelectronic device failure rate model from MIL-HDBK-217 is,

$$\lambda_P = \Pi_Q \left[C_1 \Pi_T \Pi_V + (C_2 + C_3) \Pi_E \right] \Pi_L \qquad (2\text{-}1)$$

where λ_P is the device failure rate in failures/10^6 hours
Π_Q is the quality factor

Π_T is the temperature acceleration factor

Π_V is the voltage derating stress factor

Π_E is the application environment factor

C_1 and C_2 are the circuit complexity failure rates

C_3 is the package complexity failure rate

Π_L is the learning factor

The following parameter values apply to the microelectronic devices in Table 2.1.

$\Pi_E = 4.0$
$\Pi_Q = 13.0$
$\Pi_L = 1.0$
$C_1 = 0.0053$
$\Pi_T = 0.032$
$\Pi_V = 1.0$

Table 2.1 shows an observed failure rate of 0.025×10^{-6}. Substituting in model (2-1),

$$0.025 = 13.0 \left[(.0053)(.032)(1.0) + (K)(4.0)\right] 1.0 \qquad (2\text{-}2)$$

where K is the observed value of (C_2+C_3) and was determined to be 0.00044. This value gives a general failure rate model for the microelectronic devices in this data set that allows field failure rate calculation for any desired quality and application environment factor,

$$\hat{\lambda}_p = \Pi_{Q_1} (.00017 + .00044\, \Pi_{E_1}) \quad f/10^6 \qquad (2\text{-}3)$$

where Π_{Q1} is the desired quality factor
Π_{E1} is the desired application environment

Field part fractions defective can then be estimated by

$$\text{Field Fraction Defective} = \frac{\hat{\lambda}_p \times 8580 \times 10^6}{624{,}087} \qquad (2\text{-}4)$$

where $\hat{\lambda}_p$ is determined from (2-3) and the constants are from Table 2-1. Combining (2-3) and (2-4) gives,

$$\text{Field Fraction Defective} = \Pi_{Q1} (.00017 + .00044\Pi_E) \times .0137481$$

$$= \Pi_{Q1} (2.3372 + 6.0492\Pi_E) \times 10^{-6} \qquad (2\text{-}5)$$

The total fractions defective were determined by summing the factory fraction defective (adjusted for quality factor) and field fraction defective (adjusted for both quality and application environment factors). Note that the factory application environment is always Ground, Fixed. Results are in Table 2.3.

2.2.4 Initial Fraction Defective Estimates for Other Part Types. Table 2.1 has only four part types and there is no historical data from which initial fractions defective can be estimated for other part types. Since it was assumed that there is a correlation between failure rates and fraction defective, the assumption is extended to other parts (i.e., parts with similar failure rates have similar initial fractions defective). Using this assumption, fractions defective for all part types not included in Table 2.1 are estimated on the basis of their calculated failure rates. Baseline failure rates were calculated for each part and connection type for the highest quality level available and for a Ground, Fixed application environment. See Table 2.2. Initial fractions defective were calculated for each part and connection type by scaling the microelectronic device initial fraction defective by the failure rate ratios. For example, the fraction defective for resistors was calculated by:

$$\text{Fraction Defective} = \frac{.00207 \times 10^{-6}}{.05123 \times 10^{-6}} \times 503.2\text{x}10^{-6} = 20.3 \times 10^{-6}$$

where $.00207 \times 10^{-6}$ is the resistor failure rate from Table 2.2

$.05123 \times 10^{-6}$ is the microelectronic device failure rate from Table 2.2

503.2×10^{-6} is the microelectronic device fraction defective from Table 2.3.

The fraction defective of 20.3×10^{-6} for resistors is assigned to the quality level M (see Table 2.6). The balance of the table is then generated by using 20.3×10^{-6} as the basis and extrapolating to other quality levels by using the quality factors for film resistors in MIL-HDBK-217. Extrapolation to other application environments was made by first calculating the factory fraction defective portion of the total fraction defective because that portion remains constant with environmental changes. For example, the total fraction defective for microelectronic devices is

$$= 160 + 343.2 \qquad (G_F, \text{c-1})$$

where the first term is the factory fraction defective and the second term is the field fraction defective. The corresponding terms for resistors

(G_F, M) is calculated by multiplying the terms by the failure rate ratios in Table 2.2 as follows:

$$\text{Fraction Defective (resistors, } G_F, \text{ M)} = 160 \frac{.00207}{.05123} + 343.2 \frac{.00207}{.05123}$$

$$= 6.46 + 13.87$$

In extrapolating the total fraction defective to other application environments, the first term (6.46) remains constant while the second term (13.87) is multiplied by $\pi_E/2.4$ and the two terms are then added.

This method was used to generate Tables 2.6 and 2.8 through 2.14.

2.2.5 The Effect of Application Environment on Initial Fraction Defective. There is no precise definition of what constitutes a defect but it can be reasonably assumed that a flaw which de[illegible]es to a failure during normal service life can be termed a defect. Minor flaws that survive the service life period should not be considered as defects since such flaws are indistinguishable from non-flaws. Minor flaws may survive in some benign application environments but fail in more severe environments. Therefore, each flaw present may or may not be a defect, depending on the application environment.

The relative severity of each application environment is assumed to be represented by the value of the application environment factor, Π_E, in MIL-HDBK-217. Therefore, Π_E values are used in the estimation of initial fractions defective.

Tables 2.3 through 2.14 provide the estimated values for initial fractions defective for each major part type, quality level and application environment as identified in MIL-HDBK-217.

2.2.6 Field MTBF as a Function of Defects Remaining. The observed field MTBF of equipment which contains latent defects will be less than the inherent MTBF due to the latent defects precipitating as failures in early field usage. It can be reasonably assumed that the defect failure rate is sufficiently high so that the defects will precipitate within the first thousand hours of field usage, after which no further defects remain and the equipment should exhibit its inherent MTBF.

A mathematical model which describes the expected number of failures as a function of time for an equipment which experiences random (or chance) failures and failures due to latent defects is the Chance-Defective Exponential (CDE) model[4].

The model is

$$E(t) = \lambda_g t + D(1-e^{-\bar{\lambda}_f t}) \qquad (2\text{-}8)$$

TABLE 2.2. CALCULATED FAILURE RATES FOR PARTS AND CONNECTIONS

Part or Connection Type	Calculated Failure Rate (10^{-6}) (MIL-HDBK-217D, Notice 1)
Microelectronic Device	0.05123
Resistor	0.00207
Capacitor	0.00203
Inductive Device	0.1253
Rotating Device	1.195
Relay	0.02371
Switch	0.004506
Connector	0.00852
PWB	0.07073
<u>Connections</u>	
Hand Solder	0.0026
Crimp	0.00026
Weld	0.00005
Solderless Wrap	0.0000035
Wrapped and Soldered	0.00014
Clip Termination	0.00012
Reflow Solder	0.000069

TABLE 2.3 FRACTION DEFECTIVE, MICROELECTRONIC DEVICES (DEFECTS/10^6)

	Quality Level								
Environment	S	B	B-0	B-1	B-2	C	C-1	D	D-1
GB	9.2	18.3	36.6	54.9	119.0	146.4	237.9	320.3	640.6
GF	19.4	38.7	77.4	116.1	251.6	309.6	503.2	677.3	1354.6
GM	27.5	55.1	110.1	165.2	357.9	440.5	715.8	963.6	1927.2
MP	25.6	51.2	102.4	153.6	332.9	409.7	665.8	896.3	1792.5
NSB	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
NS	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
NU	34.7	69.5	139.0	208.5	451.7	556.0	903.5	1216.2	2432.5
NH	35.7	71.4	142.8	214.3	464.3	571.4	928.5	1249.9	2499.9
NUU	37.6	75.3	150.5	225.8	489.3	602.2	978.6	1317.3	2634.6
ARW	48.2	96.4	192.9	289.3	626.9	771.6	1253.8	1687.8	3375.6
AIC	19.4	38.7	77.4	116.1	251.6	309.6	503.2	677.3	1354.6
AIT	21.8	43.5	87.0	130.5	282.9	348.1	565.7	761.5	1523.1
AIB	31.4	62.8	125.5	188.3	408.0	502.1	815.9	1098.4	2196.7
AIA	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
AIF	36.2	72.4	144.8	217.2	470.5	579.1	941.0	1266.8	2533.5
AUC	21.8	43.5	87.0	130.5	282.9	348.1	565.7	761.5	1523.1
AUT	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
AUB	43.4	86.8	173.6	260.5	564.3	694.6	1127.7	1519.4	3038.8
AUA	36.2	72.4	144.8	217.2	470.5	579.1	941.0	1266.8	2533.5
AUF	50.6	101.3	202.5	303.8	658.2	810.1	1316.4	1772.0	3544.0
SF	11.7	23.3	46.6	69.9	151.5	186.4	303.0	407.9	815.7
MFF	26.1	52.2	104.4	156.5	339.2	417.4	678.3	913.1	1826.2
MFA	33.3	66.6	133.2	199.8	433.0	532.9	866.0	1165.7	2331.4
USL	60.3	120.5	241.0	361.5	783.3	964.0	1566.6	2108.8	4217.7
ML	69.9	139.8	279.5	419.3	908.4	1118.0	1816.8	2445.7	4891.3
CL	1065.9	2131.8	4263.7	6395.5	13857.0	17054.8	27714.0	37307.4	74614.7

TABLE 2.4 FRACTION DEFECTIVE, TRANSISTORS (DEFECTS/10^6)

	Quality Level				
Environment	JANTXV	JANTX	JAN	Lower	Plastic
GB	10.9	21.9	109.3	546.6	1093.2
GF	34.6	69.2	346.0	1730.2	3460.4
GM	98.8	189.5	947.7	4738.5	9477.0
MP	65.2	130.4	651.8	3259.0	6518.0
NSB	54.3	108.7	543.3	2716.5	5433.1
NS	54.3	108.7	543.3	2716.5	5433.1
NU	109.6	219.1	1095.7	5478.3	10956.6
NH	99.7	199.4	997.0	4985.1	9970.2
NUU	104.6	209.3	1046.3	5231.7	10463.4
ARW	139.2	278.3	1391.6	6957.8	13915.6
AIC	52.9	105.7	528.5	2642.6	5285.1
AIT	80.0	160.0	799.8	3998.8	7997.5
AIB	178.6	357.2	1786.1	8930.5	17860.9
AIA	104.6	209.3	1046.3	5231.7	10463.4
AIF	203.3	406.5	2032.7	10163.4	20326.8
AUC	80.0	160.0	799.8	3998.8	7997.5
AUT	129.3	258.6	1292.9	6464.6	12929.2
AUB	301.9	603.8	3019.0	15095.1	30190.1
AUA	178.6	357.2	1786.1	8930.5	17860.9
AUF	326.6	653.1	3265.6	16328.0	32656.0
SF	8.0	15.9	79.7	398.6	797.3
MFF	65.2	130.4	651.8	3259.0	6518.0
MFA	89.8	179.7	898.4	4491.9	8983.9
USL	183.5	367.1	1835.4	9177.0	18354.1
ML	208.2	416.4	2082.0	10410.0	20819.9
CL	3408.9	6817.7	34088.7	170443.3	340886.7

TABLE 2.5 FRACTION DEFECTIVE, DIODES (DEFECTS/10^6)

Environment	Quality Level					
	JANS	JANTXV	JANTX	JAN	Lower	Plastic
GB	1.2	5.9	11.8	59.2	296.2	592.3
GF	1.7	8.6	17.2	86.0	430.0	860.0
GM	4.3	21.6	43.2	216.2	1080.8	2161.5
MP	3.2	16.1	32.2	160.8	803.8	1607.7
NSB	1.9	9.4	18.9	94.2	471.5	943.1
NS	1.9	9.4	18.9	94.3	471.5	943.1
NU	4.9	24.4	48.8	243.8	1219.2	2438.5
NH	4.5	22.5	45.1	225.4	1126.9	2253.8
NUU	4.7	23.5	46.9	234.6	1173.1	2346.2
ARW	6.0	29.9	59.8	299.2	1496.2	2992.3
AIC	3.8	18.8	37.7	188.5	942.3	1884.6
AIT	4.7	23.5	46.9	234.6	1173.1	2346.2
AIB	6.5	32.7	65.4	326.9	1634.6	3269.2
AIA	5.6	28.1	56.2	280.8	1403.8	2807.7
AIF	7.5	37.3	74.6	373.1	1865.4	3730.8
AUC	5.6	28.1	56.2	280.8	1403.8	2807.7
AUT	6.5	32.7	65.4	326.9	1634.6	3269.2
AUB	10.2	51.2	102.3	511.5	2557.7	5115.4
AUA	8.4	41.9	83.8	419.2	2096.2	4192.3
AUF	10.2	51.2	102.3	511.5	2557.7	5115.4
SF	1.2	5.9	11.8	59.2	296.2	592.3
MFF	3.2	16.1	32.2	160.8	803.8	1607.7
MFA	4.1	20.7	41.4	206.9	1034.6	2069.2
USL	7.6	38.2	76.5	382.3	1911.5	3823.1
ML	8.6	42.8	85.7	428.5	2142.3	4284.6
CL	128.4	641.9	1283.8	6419.2	32096.2	64192.3

TABLE 2.6 FRACTION DEFECTIVE, RESISTORS (DEFECTS/10^6)

	Quality Level					
Environment	S	R	P	M	MIL-SPEC	Lower
GB	0.4	1.2	3.7	12.3	61.4	184.2
GF	0.6	2.0	6.1	20.3	101.7	305.2
GM	1.5	5.1	15.4	51.5	257.4	772.3
MP	1.7	5.7	17.2	57.2	286.2	858.7
NSB	0.9	3.1	9.2	30.7	153.6	460.9
NS	1.0	3.4	10.1	33.6	168.1	504.2
NU	2.6	8.7	26.2	87.2	436.2	1308.5
NH	2.6	8.7	26.2	87.2	436.2	1308.5
NUU	2.8	9.3	27.9	93.0	465.0	1395.0
ARW	3.5	11.6	34.8	116.1	580.3	1740.9
AIC	0.6	2.1	6.3	20.9	104.6	313.9
AIT	0.7	2.4	7.1	23.8	119.0	357.1
AIB	1.3	4.4	13.2	44.0	219.9	659.8
AIA	1.2	4.1	12.3	41.1	205.5	616.6
AIF	1.8	5.8	17.5	58.4	292.0	876.0
AUC	1.4	4.7	14.1	46.9	234.4	703.1
AUT	1.3	4.4	13.2	44.0	219.9	659.8
AUB	2.8	9.3	27.9	93.0	465.0	1395.0
AUA	2.8	9.3	27.9	93.0	465.0	1395.0
AUF	3.7	12.2	36.5	121.8	609.1	1827.4
SF	0.3	0.9	2.6	8.8	44.1	132.3
MFF	1.7	5.8	17.3	57.8	289.1	867.4
MFA	2.3	7.6	22.7	75.7	378.5	1135.5
USL	4.7	15.6	46.9	156.4	782.1	2346.3
ML	5.4	17.9	53.8	179.5	897.4	2692.2
CL	88.4	294.7	884.1	2947.0	14735.0	44205.0

TABLE 2.7 FRACTION DEFECTIVE, CAPACITORS (DEFECTS/10^6)

	Quality Level						
Environment	S	R	P	M	L	MIL-SPEC	Lower
GB	1.2	3.8	11.5	38.4	115.3	115.3	384.4
GF	1.8	6.2	18.4	61.5	184.5	184.5	615.0
GM	9.0	30.0	89.9	299.8	899.4	899.4	2998.1
MP	12.7	42.3	126.8	422.8	1268.4	1268.4	4228.1
NSB	5.8	19.2	57.7	192.2	576.6	576.6	1921.9
NS	6.3	21.1	63.4	211.4	634.2	634.2	2114.1
NU	14.3	47.7	143.0	476.6	1429.9	1429.9	4766.2
NH	18.4	61.5	184.5	615.0	1845.0	1845.0	6150.0
NUU	20.8	69.2	207.6	691.9	2075.6	2075.6	6918.7
ARW	27.7	92.2	276.7	922.5	2767.5	2767.5	9225.0
AIC	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIT	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIB	5.8	19.2	57.7	192.2	576.6	576.6	1921.9
AIA	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIF	6.9	23.1	69.2	230.6	691.9	691.9	2306.2
AUC	8.6	28.8	86.5	288.3	864.8	864.8	2882.8
AUT	9.2	30.7	92.2	307.5	922.5	922.5	3075.0
AUB	11.5	38.4	115.3	384.4	1153.1	1153.1	3843.7
AUA	9.2	30.7	92.2	307.5	922.5	922.5	3075.0
AUF	17.3	57.7	173.0	576.6	1729.7	1729.7	5765.6
SF	0.9	3.1	9.2	30.7	92.2	92.2	307.5
MFF	12.7	42.3	126.8	422.8	1268.4	1268.4	4228.1
MFA	17.3	57.7	173.0	576.6	1729.7	1729.7	5765.6
USL	36.9	123.0	369.0	1230.0	3690.0	3690.0	12300.0
ML	41.5	138.4	415.1	1383.7	4151.2	4151.2	13837.5
CL	703.4	2344.7	7034.1	23446.9	70340.6	70340.6	234468.6

TABLE 2.8 FRACTION DEFECTIVE, INDUCTIVE DEVICES (DEFECTS/10^6)

Environment	Quality Level	
	MIL-SPEC	Lower
GB	537.2	1790.7
GF	1222.9	4076.4
GM	1996.1	7140.1
MP	2142.0	6653.8
NSB	1135.4	3784.6
NS	1222.9	4076.4
NU	2433.8	8112.7
NH	2725.6	9085.3
NUU	3017.4	10058.0
ARW	3892.7	12975.8
AIC	1047.8	3492.8
AIT	1266.7	4222.3
AIB	1266.7	4222.3
AIA	1266.7	4222.3
AIF	1704.4	5681.2
AUC	1339.6	4465.4
AUT	1339.6	4465.4
AUB	1485.5	4951.7
AUA	1485.5	4951.7
AUF	1850.3	6167.5
SF	537.2	1790.7
MFF	1996.1	6653.8
MFA	2579.7	8599.0
USL	5059.9	16866.2
ML	5643.4	18811.5
CL	89385.3	297951.1

TABLE 2.9 FRACTION DEFECTIVE, ROTATING DEVICES

Environment	Fraction defective (Defects/10^6)
GB	5935.2
GF	11663.1
GM	30168.5
MP	27965.5
NSB	14967.6
NS	16289.4
NU	34574.6
NH	38980.6
NUU	43386.7
ARW	56604.8
AIC	12544.3
AIT	13645.8
AIB	15848.8
AIA	13645.8
AIF	23559.4
AUC	14747.3
AUT	18051.9
AUB	20254.9
AUA	18051.9
AUF	25762.5
SF	5935.2
MFF	27965.5
USL	74229.1
ML	83041.2
CL	*******

TABLE 2.10 FRACTION DEFECTIVE, RELAYS (DEFECTS/10^6)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	142.5	210.9
GF	231.4	388.8
GM	635.1	1784.5
MP	1510.8	4384.3
NSB	621.4	1716.0
NS	621.4	1716.0
NU	1031.9	2673.9
NH	2263.4	6642.0
NUU	2400.2	6915.7
ARW	3221.2	9652.3
AIC	450.3	724.0
AIT	484.5	1100.3
AIB	758.2	1442.4
AIA	587.2	1100.3
AIF	758.2	1784.5
AUC	621.4	1442.4
AUT	689.8	1784.5
AUB	1100.3	2810.7
AUA	758.2	2126.5
AUF	1100.3	3152.8
SF	142.5	210.9
MFF	1510.8	4384.3
MFA	2058.1	5684.2
USL	4315.8	13073.1
ML	4931.6	14441.4
CL	N/A	N/A

TABLE 2.11 FRACTION DEFECTIVE, SWITCHES (DEFECTS/10^6)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	1.4	24.4
GF	2.4	44.0
GM	8.8	158.4
MP	12.8	230.6
NSB	5.3	95.5
NS	5.3	95.5
NU	12.2	220.3
NH	19.1	344.1
NUU	20.3	364.7
ARW	27.1	488.4
AIC	5.4	96.6
AIT	5.4	96.6
AIB	9.4	168.8
AIA	9.4	168.8
AIF	12.2	220.3
AUC	6.5	117.2
AUT	6.5	117.2
AUB	12.2	220.3
AUA	12.2	220.3
AUF	15.1	271.9
SF	1.4	24.4
MFF	12.8	230.6
MFA	17.4	313.1
USL	36.9	663.7
ML	41.5	746.2
CL	688.3	12388.6

TABLE 2.12 FRACTION DEFECTIVE, CONNECTORS (DEFECTS/10^6)

Environment	Quality Level MIL-SPEC	Lower
GB	73.7	97.3
GF	83.2	248.1
GM	417.7	1204.6
MP	427.1	827.7
NSB	219.8	408.3
NS	276.3	544.9
NU	639.2	1298.9
NH	639.2	1251.8
NUU	686.3	1346.0
ARW	921.9	1770.1
AIC	120.9	497.8
AIT	168.0	497.8
AIB	238.7	733.4
AIA	215.1	733.4
AIF	332.9	969.0
AUC	262.2	733.4
AUT	403.6	733.4
AUB	497.8	969.0
AUA	474.3	969.0
AUF	733.4	1440.2
SF	73.7	97.3
MFF	427.1	827.7
MFA	592.1	1157.5
USL	1204.6	2382.7
ML	1393.1	2759.6
CL	23115.8	45733.8

TABLE 2.13 FRACTION DEFECTIVE, PRINTED WIRING BOARDS (DEFECTS/10^6)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	425.0	4250.0
GF	690.3	6903.2
GM	1792.4	17924.3
MP	1629.2	16291.5
NSB	1057.7	10576.9
NS	1302.6	13026.0
NU	2670.0	26700.3
NH	2874.1	28741.2
NUU	3078.2	30782.2
ARW	4098.7	40986.9
AIC	731.1	7311.4
AIT	1139.3	11393.2
AIB	1853.7	18536.5
AIA	1567.9	15679.2
AIF	2261.8	22618.4
AUC	1751.6	17516.1
AUT	3282.3	32823.1
AUB	5323.3	53232.5
AUA	4302.8	43027.8
AUF	7364.2	73641.9
SF	425.0	4250.0
MFF	1996.5	19965.2
MFA	2670.0	26700.3
USL	5527.3	55273.5
ML	6139.6	61396.3
CL	102267.9	*******

TABLE 2.14 FRACTION DEFECTIVE, CONNECTIONS (DEFECTS/10^6)

Environment	Connection Type									
							Crimp			
	Hand Solder	Weld	Solderless Wrap	Wrapped and Soldered	Clip Term	Reflow Solder	Auto	Man., Upper	Man., Std.	Man., Lower
GB	12.	0.2	0.02	1.	1.	0.3	1.2	1.2	2.5	24.8
GF	26.	0.5	0.03	1.	1.	0.7	2.6	2.6	5.2	52.0
GM	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
MP	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
NSB	43.	0.8	0.06	2.	2.	1.1	4.3	4.3	8.7	86.7
NS	54.	1.0	0.07	3.	3.	1.4	5.4	5.4	10.9	109.0
NU	123.	2.4	0.16	7.	6.	3.3	12.3	12.3	24.5	245.1
NH	136.	2.6	0.18	7.	6.	3.6	13.6	13.6	27.2	272.4
NUU	149.	2.9	0.20	8.	7.	3.9	14.9	14.9	29.7	297.1
ARW	198.	3.8	0.27	11.	9.	5.3	19.8	39.6	39.6	396.2
AIC	31.	0.6	0.04	2.	1.	0.8	3.1	3.1	6.2	61.9
AIT	56.	1.1	0.07	3.	3.	1.5	5.6	5.6	11.1	111.4
AIB	68.	1.3	0.09	4.	3.	1.8	6.8	6.8	13.6	136.2
AIA	62.	1.2	0.08	3.	3.	1.6	6.2	6.8	12.4	123.8
AIF	93.	1.8	0.12	5.	4.	2.5	9.3	9.3	18.6	185.7
AUC	37.	0.7	0.05	2.	2.	1.0	3.7	3.7	7.4	74.3
AUT	74	1.4	0.10	4.	3.	2.0	7.4	7.4	14.9	148.6
AUB	93.	1.8	0.12	5.	4.	2.5	9.3	9.3	18.6	185.7
AUA	87.	1.7	0.12	5.	4.	2.3	8.7	8.7	17.3	173.3
AUF	118.	2.3	0.16	6.	5.	3.1	11.8	11.8	23.5	235.2
SF	12.	0.2	0.02	1.	1.	0.3	1.2	2.5	2.5	24.8
MFF	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
MFA	124.	2.4	0.17	7.	6.	3.3	12.4	12.4	24.8	247.6
USL	272.	5.2	0.37	15.	13.	7.2	27.2	27.2	54.5	544.8
ML	310.	6.0	0.42	17.	14.	8.2	31.0	31.0	61.9	619.0
CL	5200.	100.0	7.0	280.	240.	138.0	520.0	520.0	1040.0	10400.0

where $E(t)$ is the expected number of failures in time, t. The first term on the right-hand side is the number failures in t resulting from good parts (chance failures) and the second term is the number of failures in t resulting from latent defects. D is the number of defects initially present and $\bar{\lambda}_f$ is the defect average failure rate. Failure rates of good parts and defects are assumed constant.

The cumulative MTBF versus time for equipment with latent defects can be calculated by $t/E(t)$, time divided by expected number of failures. Figures 2.2 and 2.3 show the cumulative MTBF for an equipment with an inherent MTBF of 200 hours ($\lambda_g = .005$) for varying quantities of remaining defects present. A defect failure rate of 10^{-3} is assumed for these examples.

It can be seen in Figure 2.2 that in excess of 10,000 hours are required for the cumulative MTBF to approach the inherent MTBF with as few as 5 defects initially present.

The observed MTBF is cumulative, i.e., total operating hours divided by total failures, which include the 5 remaining defects which precipitate well within the first 1,000 hours of operation. In moving window calculations which exclude the first 1,000 hours of operation, MTBF values approaching the inherent reliability will be observed. This is shown by the instantaneous failure rate curves in Figure 2.4, calculated from,

$$\lambda = \lambda_g + D\bar{\lambda}_f e^{-\bar{\lambda}_f t} \qquad (2\text{-}9)$$

Figure 2.4 also shows that the instantaneous failure rate corresponding to the inherent reliability is rapidly achieved, independent of the number of defects remaining.

A 200-hour MTBF system was examined and found to include the following:

247 Printed Wiring Assemblies
146 Discrete Wiring Assemblies
23,381 Electrical Parts
37,849 Mechanical Parts
136,000 Wave Solder Connections
43,000 Solderless Wrap Connections
3,000 Crimp Connections
131,000 Hand Solder Connections
2,000 Coax Connections

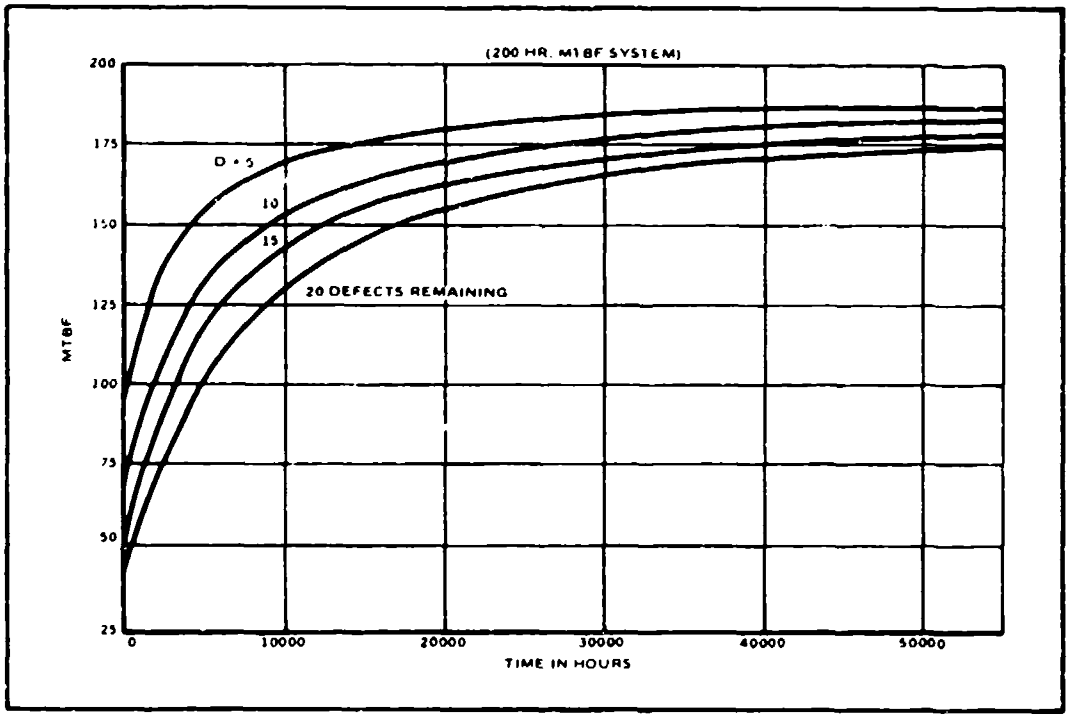

Figure 2.2. Cumulative MTBF versus Time for a Large Quantity of Remaining Defects

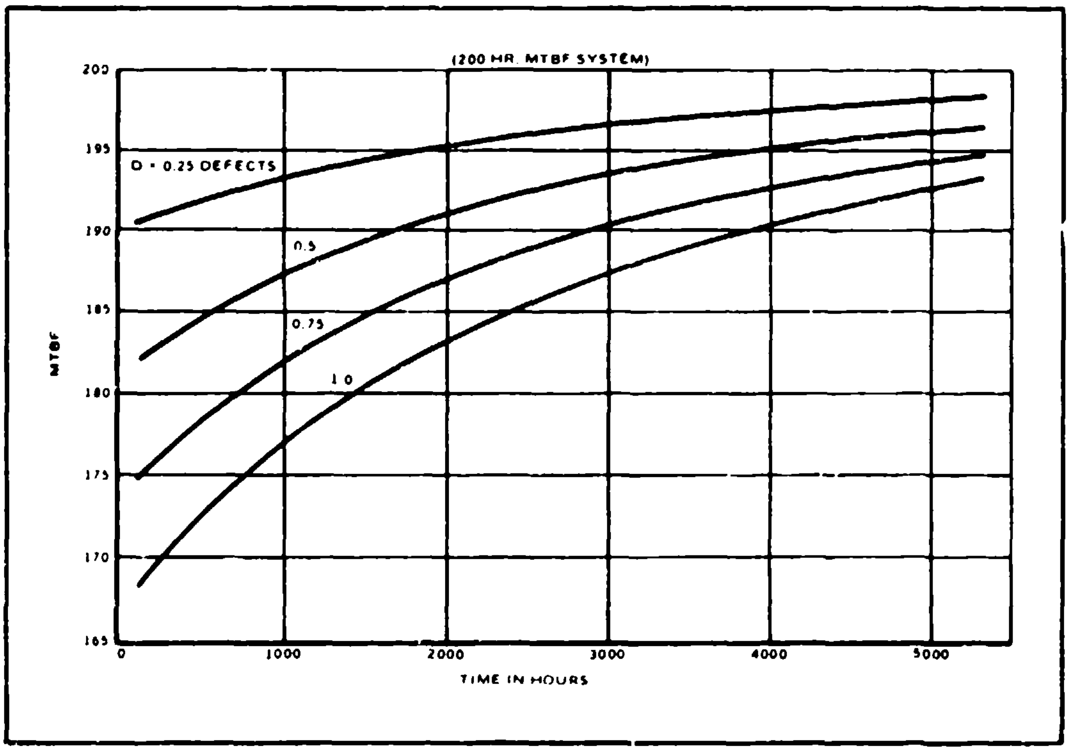

Figure 2.3. Cumulative MTBF versus Time for a Small Quantity of Remaining Defects

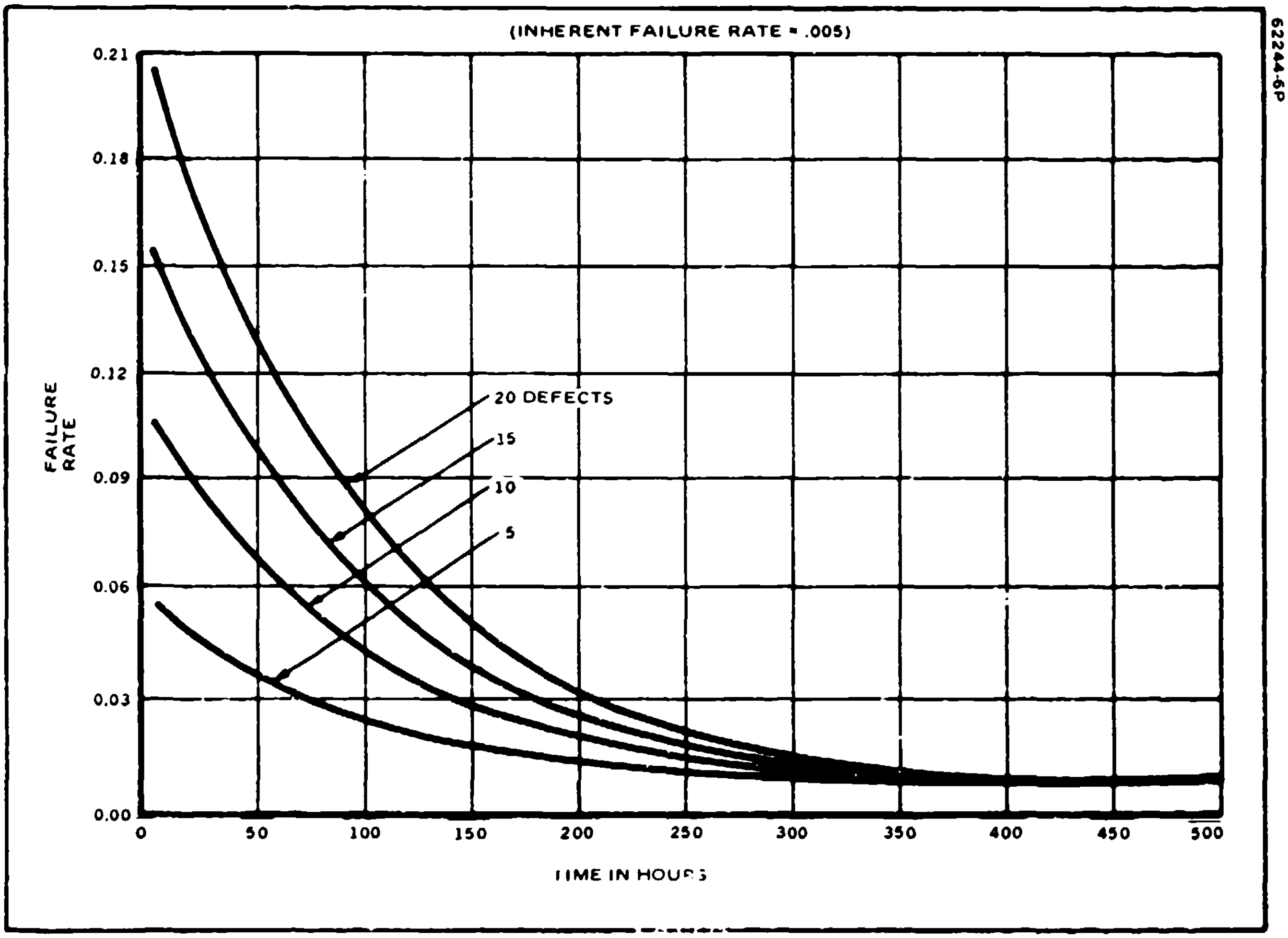

Figure 2.4. Failure Rates versus Time for Equipment with Remaining Defects

Figure 2.3 shows that a system with greater than 90% of the inherent 200-hour MTBF can be produced if the remaining number of defects at the completion of the production process is 0.5 (per system). Assuming the defect distribution is proportional to predicted failure rates, the quality of the production process must be such that the escaping defect rates do not exceed the following:

electrical parts = 20 defects/million parts
mechanical parts = 0.1 defects/million parts
electrical connections = 0.2 defects/million connections

Based on limited research and analysis of data during the first 1,000 hours of operation of mature military electronic systems, the escaping defect rates for mechanical parts and electrical connections appear to be one or two orders of magnitude greater than required based on the allocations derived above. The electrical part defect rates also exceed their allocated value by as much as seven (7) times greater. (See Table 2.15). This indicates a need for improved production process controls and, perhaps, stress screening, without which field MTBFs will be significantly below the required during the first 1000 hours of operation.

2.3 Estimating Test Strength.

2.3.1 Definition of Test Strength. Test strength is a measure of the effectiveness of a stress screen to precipitate a defect into a detectable failure and to detect the failure to permit its removal. Test strength is the product of screening strength and probability of detection,

$$TS = SS \times P_D$$

where

SS is Screening Strength, defined as the probability that a screen will precipitate a defect into a detectable failure, given that a defect is present.

P_D is the Probability of Detection and is the probability that a failure will be detected, given that a failure is present.

In the following paragraphs, the derivations of screening strengths and probabilities of detection are described.

2.3.2 Data Sources. While there is a considerable amount of stress screening activity, particularly by defense contractors, there is little actual stress screening data that can be used to estimate the effectiveness

TABLE 2.15. OBSERVED DEFECTS DURING FIRST 1,000 HOURS OF OPERATION

System	Observed Defect Rates (ppm)		
	Elect. Parts	Mech. Parts	Elect. Connections
Radar 1	87.0	8.8	1.9
Data Converter	28.2	6.8	1.2
Communications Terminal	145.7	25.6	3.8
Display Console 1	126.6	23.7	5.3
Display Console 2	50.0	6.9	1.3
Weighted Average	100.9	15.3	4.2

of the screens used. In order to determine stress screening effectiveness, the following conditions are required:

a. The item subjected to stress screening must be tested thoroughly before the stress screen to assure that no detectable failures remain at the start of stress screening. Not testing before stress screening results in ambiguity as to the source of failures detected after screening, i.e., it is not known if the failures were present before the stress screen or if they were precipitated by the stress screen.

b. The item subjected to stress screening must be powered and exercised in as close to normal operating conditions as possible and performance must be continuously monitored to assure that stress-dependent defects (e.g., intermittents, temperature and timing sensitive faults) are detected.

c. The item subjected to stress screening must be tested after the stress screen, using the same test(s) used before the stress screen to assure that the failures detected are a result of the stress screen.

d. Data must be collected on defect fallout subsequent to the stress screen (i.e., during subsequent stress screens, tests, or early field operation) to get a measure of the number of defects remaining.

2.3.2.1 Temperature Cycling Screening Data. Screening strength equations were developed in Ref. 1 for temperature and vibration screens. The temperature screens were based on limited data and were revised in this study on the basis of data in Ref. 5, which describes the results of stress screening of over 1000 avionic systems which, along with the line-replaceable units (LRU) were subjected to the stress screens shown in Table 2.16. LRUs were tested at each temperature cycle and fallout was recorded. Results are shown in Table 2.17. Over 3000 LRUs were subjected to stress screens and over 700 failures were detected. Ref. 5 also includes failure data from testing subsequent to stress screening which provides a measure of stress screening effectiveness.

2.3.2.2 Vibration Screening Data. Ref. 6 provides the only known source of quantitative vibration screening effectiveness data. Results of the experiments described in that report have been widely accepted (e.g., NAVMAT P-9492) and were used in this study to develop screening strength equations).

2.3.3 Screening Strength of Vibration Screens. The screening strength equations in Ref. 1 were derived from the experimental results in Ref. 6. In this study, the same data was used but the form of the equation was changed to

$$SS = 1 - e^{-xt}$$

TABLE 2.16. STRESS SCREENS APPLIED TO AVIONICS LINE REPLACEABLE UNITS (Ref. 5)

Vibration Screen				Temperature Cycling Screen			
LRU	Type	g-level	Duration in min/cycle	Extremes in °C	Rate of Change in °C/min	Time in hours per cycle	Number of Cycles
A,B	Single Frequency	1.0	40	-54 +71	5	8	12 12
C,D	Single Frequency	2.2	20	-60 +71	5	5.5	3 7
E	Single Frequency	1.67	50	-54 +71	5	8	9
F	Single Frequency	1.67	20	-54 +71	5	4	6
G,H	Single Frequency	1.65	60	-54 +71	5	5.5	2

TABLE 2.17. STRESS SCREENING FALLOUT DATA[5] AND OBSERVED TEST STRENGTHS

		Temperature Cycle												
LRU		1	2	3	4	5	6	7	8	9	10	11	12	Total Fallout
A	Failures	34	12	14	7	8	7	7	7	5	12	5	3	121
	Units Screened	198	169	159	147	141	134	128	122	116	112	102	98	
	Test Strength	.281	.380	.496	.554	.620	.678	.736	.793	.835	.934	.975	1.000	
B	Failures	24	13	12	5	3	5	5	3	3	3	3	3	82
	Units Screened	199	183	174	166	163	161	158	155	153	151	149	147	
	Test Strength	.293	.451	.598	.659	.695	.756	.817	.854	.890	.927	.963	1.000	
C_1	Failures	86	5	4	2									97
	Units Screened	217	121	116	69									
	Test Strength	.570	.603	.629	.642									
C_2	Failures	19	7	7	5	4	4	8						54
	Units Screened	219	199	192	185	180	176	172						
	Test Strength	.352	.481	.611	.704	.778	.852	1.000						
D	Failures	14	6	2	3	1	3	1	0	3				33
	Units Screened	186	172	166	164	161	160	157	156	156				
	Test Strength	.424	.606	.667	.758	.788	.879	.909	.909	1.000				

TABLE 2.17. STRESS SCREENING FALLOUT DATA[6] AND OBSERVED TEST STRENGTHS (Cont)

LRU		Temperature Cycle 1	2	3	4	5	6	7	8	9	10	11	12	Total Fallout
E	Failures	6	2	3	0	2	1	1	0	1				16
	Units Screened	186	180	178	175	175	173	172	171	171				
	Test Strength	.375	.500	.688	.688	.813	.875	.938	.938	1.000				
F	Failures	50	5	18	92	0	22							187
	Units Screened	744	694	689	671	579	579							
	Test Strength	.267	.294	.390	.882	.882	1.000							
G	Failures	52	0	35	40	0	8							135
	Units Screened	1116	1064	1064	1029	989	989							
	Test Strength	.385	.385	.644	.941	.941	1.000							
H	Failures	4	4											8
	Units Screened	186	182											
	Test Strength	.500	1.000											
I	Failures	11	4											15
	Units Screened	186	175											
	Test Strength	.733	1.000											

to correct some boundary problems with the previous form. Data sets were generated using the original screening strength equations and the new form of the equations was fitted to the data sets using a non-linear least squares technique. The resulting equations are provided below.

2.3.3.1 Random Vibration Screening Strength. The screening strength equation for random vibration stress screens is

$$SS_{RV} = 1 - \exp[-.0046(G)^{1.71}(t)] \quad (2\text{-}10)$$

where

G = g-rms. This is the rms value of the applied power (power spectral density) over the vibration frequency spectrum.

t = Time. This is the duration of the applied vibration excitation, in minutes.

Screening strength values are shown in Table 2.18.

2.3.3.2 Swept-Sine Vibration Screening Strength. The screening strength equation for swept-sine vibration stress screens is

$$SS_{SSV} = 1 - [-.000727\ (G)^{0.863}(t)] \quad (2\text{-}11)$$

where

G = g-level. This is the constant acceleration applied to the equipment being screened throughout the frequency range above 40 Hz. The g-level below 40 Hz may be less.

t = Time, in minutes.

Screening strength values are shown in Table 2.19.

2.3.3.3 Single Frequency Vibration Screening Strength. The screening strength equation for single frequency vibration stress screens is

$$SS_{SFV} = 1 - \exp[-.00047(G)^{0.490}(t)] \quad (2\text{-}12)$$

where

G = g-level.
t = Time, in minutes.

2.3.4 Screening Strength of Temperature Screens. Test strengths were calculated for each temperature cycle for each LRU data set in Table 2.17 by dividing the cumulative screening fallout at each cycle by the total number of defects present in the LRU at the start of the screen. For example, the test strength of the first cycle of the LRU A stress screen is 34 divided by 121, or 0.281. For the second cycle, test strength is 34 plus 12 divided by

TABLE 2.18. SCREENING STRENGTH, RANDOM VIBRATION SCREENS

Duration	G-RMS Level													
(minutes)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
5	0.007	0.023	0.045	0.072	0.104	0.140	0.178	0.218	0.260	0.303	0.346	0.389	0.431	0.473
10	0.014	0.045	0.088	0.140	0.198	0.260	0.324	0.389	0.452	0.514	0.572	0.627	0.677	0.723
15	0.021	0.067	0.129	0.202	0.282	0.363	0.444	0.522	0.595	0.661	0.720	0.772	0.816	0.854
20	0.028	0.088	0.168	0.260	0.356	0.452	0.543	0.626	0.700	0.764	0.817	0.861	0.896	0.923
25.	0.035	0.109	0.206	0.314	0.424	0.529	0.625	0.708	0.778	0.835	0.880	0.915	0.941	0.959
30.	0.041	0.129	0.241	0.363	0.484	0.595	0.691	0.772	0.836	0.885	0.922	0.948	0.966	0.979
35.	0.048	0.149	0.275	0.409	0.538	0.651	0.746	0.822	0.878	0.920	0.949	0.968	0.981	0.989
40.	0.055	0.168	0.308	0.452	0.586	0.700	0.791	0.860	0.910	0.944	0.966	0.981	0.989	0.994
45.	0.061	0.187	0.339	0.492	0.629	0.742	0.829	0.891	0.933	0.961	0.978	0.988	0.994	0.997
50.	0.068	0.205	0.369	0.529	0.668	0.778	0.859	0.915	0.951	0.973	0.986	0.993	0.996	0.998
55.	0.074	0.224	0.397	0.563	0.702	0.809	0.884	0.933	0.964	0.981	0.991	0.996	0.998	0.999
60.	0.081	0.241	0.424	0.595	0.734	0.836	0.905	0.948	0.973	0.987	0.994	0.997	0.999	1.000
$\overline{\lambda}_f$	0.084	0.276	0.552	0.903	1.322	1.806	2.351	2.954	3.613	4.327	5.092	5.905	6.776	7.692

TABLE 2.19. SCREENING STRENGTH, SWEPT-SINE VIBRATION SCREENS

Duration (minutes)	G Level													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
5.	0.0020	0.0036	0.0051	0.0066	0.0080	0.0093	0.0107	0.0120	0.0132	0.0145	0.0157	0.0169	0.0181	0.0193
10.	0.0040	0.0072	0.0103	0.0131	0.0159	0.0186	0.0212	0.0238	0.0263	0.0287	0.0312	0.0335	0.0359	0.0382
15.	0.0060	0.0108	0.0154	0.0196	0.0238	0.0278	0.0316	0.0354	0.0391	0.0428	0.0464	0.0499	0.0534	0.0568
20.	0.0080	0.0144	0.0204	0.0261	0.0316	0.0368	0.0420	0.0470	0.0519	0.0566	0.0614	0.0660	0.0705	0.0750
25.	0.0099	0.0180	0.0255	0.0325	0.0393	0.0458	0.0522	0.0584	0.0644	0.0703	0.0761	0.0818	0.0874	0.0929
30.	0.0119	0.0216	0.0305	0.0389	0.0470	0.0547	0.0623	0.0696	0.0768	0.0838	0.0906	0.0973	0.1039	0.1104
35.	0.0139	0.0251	0.0355	0.0452	0.0546	0.0636	0.0723	0.0807	0.0890	0.0970	0.1049	0.1126	0.1201	0.1275
40.	0.0159	0.0287	0.0404	0.0515	0.0621	0.0723	0.0822	0.0917	0.1010	0.1101	0.1189	0.1276	0.1361	0.1444
45.	0.0178	0.0322	0.0454	0.0578	0.0696	0.0810	0.0919	0.1026	0.1129	0.1230	0.1328	0.1424	0.1517	0.1609
50.	0.0198	0.0357	0.0503	0.0640	0.0770	0.0895	0.1016	0.1133	0.1246	0.1357	0.1464	0.1569	0.1671	0.1771
55.	0.0217	0.0392	0.0552	0.0701	0.0844	0.0980	0.1112	0.1239	0.1362	0.1482	0.1598	0.1711	0.1822	0.1930
60.	0.0237	0.0427	0.0600	0.0763	0.0917	0.1065	0.1207	0.1344	0.1476	0.1605	0.1730	0.1852	0.1970	0.2085
$\bar{\lambda}_f$	0.0240	0.0436	0.0619	0.0793	0.0962	0.1126	0.1286	0.1443	0.1597	0.1749	0.1899	0.2048	0.2194	0.2339

121, or 0.380. In the stress screens for LRUs A and B there were some failures detected during a post-screen test and it is assumed that those failures were actually precipitated by the screens but were undetected until the more thorough post-screen test was conducted. The post-screen failures were distributed among the screening fallout in proportion to the fallout at each cycle. The test strengths thus generated represent composite test strengths (a combined strength of temperature cycling and single frequency vibration) for the screens and the vibration strength must be extracted to give the temperature cycle test strength. Composite test strength is given by

$$TS_C = 1 - (1 - TS_{TC})(1 - TS_{SFV})$$

where

TS_{TC} is the temperature cycle test strength
TS_{SFV} is the single frequency vibration test strength.

But it is desired to determine the screening strength rather than the test strength so with the assumption of a 0.95 value for probability of detection (a realistic value for power on screening, test at each cycle, and a thorough post-screen test), the composite test strength equation can be rewritten as

$$TC_C = 1 - [1 - .95(SS_{TC})][1 - .95(SS_{SFV})]$$

and

$$SS_{TC} = \frac{1}{.95}\left[1 - \frac{1 - TS_C}{1 - .95(SS_{SFV})}\right] \qquad (2\text{-}13)$$

Since TS_C is known from the data set (Table 2.17) and SS_{SFV} can be calculated from the equation in para. 2.3.3.3 using the parameters in Table 2.16, the values of SS_{TC} at each temperature cycle can be calculated to generate a new data set. This data is then fitted to the temperature cycle screening strength equation using a non-linear least squares technique.

The form of the temperature cycle screening strength equation is basically the same as that developed in Ref. 1,

$$SS_{TC} = 1 - \exp\left\{-K(R + 0.6)^{0.6}[\ln(\ell + DT)]^3(N_{cyc})\right\}$$

where

R = Range. This is the difference between the maximum and minimum applied external (chamber) temperature or inlet cooling air temperature for independently cooled items. ($T_{max} - T_{min}$). Temperatures are in °C.

DT = Temperature Rate of Change. This is the average value of the temperature rate of change of the item being screened as it transitions between the temperature extremes. DT is in °C/minute.

$$DT = \left[\left(\frac{T_{max} - T_{min}}{t_1}\right) + \left(\frac{T_{max} - T_{min}}{t_2}\right)\right] \div 2$$

where

t_1 = is the transition time from T_{min} to T_{max} (in minutes)
t_2 = is the transition time from T_{max} to T_{min} (in minutes)
N_{cyc} = number of temperature cycles
K = is the constant to be fitted by the data set.

The non-linear least squares technique used (SAS NLIN, Ref. 8) first tests a range of possible values of K and calculates the residual sum of squares for each. The Marquardt method was used by the routine to continue the process to progress from the starting values to a value of K that minimized the squared distance from the data set points to the corresponding points calculated by the use of K (Least squares method). The estimate of K so produced is 0.0017. The 95 percent confidence interval for K is .0015 to .00189, indicating a good estimate for K. The resulting screening strength equation is

$$SS_{TC} = 1 - \exp\{-.0017(R + 0.6)^{0.6}[\ln(e + DT)]^3(N_{cyc})\} \qquad (2.14)$$

Screening strength values are shown in Table 2.20.

The constant temperature screen (one in which the item to be screened is subjected to single, unvarying temperature) is considered to be a limiting case of a temperature cycle screen in which the maximum and minimum temperatures converge to a single temperature ($T_{max} = T_{min}$), the temperature rate of change reduces to zero, and the number of cycles reduces to 1. The constant temperature screening strength equation derived from the temperature cycle screening strength equation is

$$SS_{CT}\ 1 - \exp[-.0017(R + 0.6)^{0.6}(t)] \qquad (2\text{-}15)$$

where

R is the temperature range defined as the absolute value of the difference between the screening temperature (in °C) and 25°C.

t is the screening time in hours.

Screening strength values are shown in Table 2.22.

TABLE 2.20. SCREENING STRENGTH, TEMPERATURE CYCLING SCREENS

Number of Cycles		Temperature Range (R)								
		20.	40.	60.	80.	100.	120.	140.	160.	180.
2.	DT =									
	5.	.1633	.2349	.2886	.3324	.3697	.4023	.4312	.4572	.4809
	10.	.2907	.4031	.4812	.5410	.5891	.6290	.6629	.6920	.7173
	15.	.3911	.5254	.6124	.6752	.7232	.7612	.7920	.8175	.8388
	20.	.4707	.6155	.7034	.7636	.8075	.8407	.8665	.8871	.9037
4.	DT =									
	5.	.2998	.4147	.4939	.5543	.6027	.6427	.6765	.7054	.7305
	10.	.4969	.6437	.7308	.7893	.8312	.8624	.8863	.9051	.9201
	15.	.6292	.7748	.8498	.8945	.9234	.9430	.9567	.9667	.9740
	20.	.7198	.8522	.9120	.9441	.9629	.9746	.9822	.9873	.9907
6.	DT =									
	5.	.4141	.5522	.6400	.7025	.7496	.7864	.8160	.8401	.8601
	10.	.6431	.7873	.8603	.9033	.9306	.9489	.9617	.9708	.9774
	15.	.7742	.8931	.9418	.9657	.9788	.9864	.9910	.9939	.9958
	20.	.8517	.9432	.9739	.9868	.9929	.9960	.9976	.9986	.9991
8.	DT =									
	5.	.5098	.6574	.7439	.8014	.8422	.8723	.8953	.9132	.9274
	10.	.7469	.8731	.9275	.9556	.9715	.9811	.9871	.9910	.9936
	15.	.8625	.9493	.9774	.9889	.9941	.9967	.9981	.9989	.9993
	20.	.9215	.9781	.9923	.9969	.9986	.9994	.9997	.9998	.9999
10.	DT =									
	5.	.5898	.7379	.8178	.8674	.9005	.9237	.9405	.9529	.9623
	10.	.8204	.9242	.9624	.9796	.9883	.9930	.9956	.9972	.9982
	15.	.9163	.9759	.9913	.9964	.9984	.9992	.9996	.9998	.9999
	20.	.9585	.9916	.9977	.9993	.9997	.9999	.9999	.9999	.9999
12.	DT =									
	5.	.6568	.7994	.8704	.9115	.9373	.9544	.9661	.9744	.9804
	10.	.8726	.9548	.9805	.9906	.9952	.9974	.9985	.9991	.9995
	15.	.9490	.9886	.9966	.9988	.9996	.9998	.9999	.9999	.9999
	20.	.9780	.9968	.9993	.9998	.9999	.9999	.9999	.9999	.9999

TABLE 2.21. $\bar{\lambda}_f$ VALUES FOR TEMPERATURE CYCLING SCREENS

Rate of Change	Temperature Range (R)								
	20.	40.	60.	80.	100.	120.	140.	160.	180.
DT =									
5.	0.0891	0.1339	0.1703	0.2020	0.2308	0.2573	0.2821	0.3055	0.3278
10.	0.1717	0.2580	0.3281	0.3893	0.4447	0.4958	0.5436	0.5888	0.6317
15.	0.2480	0.3726	0.4739	0.5623	0.6423	0.7161	0.7852	0.8504	0.9125
20.	0.3181	0.4779	0.6077	0.7212	0.8237	0.9184	1.0070	1.0906	1.1702

TABLE 2.22. SCREENING STRENGTH, CONSTANT TEMPERATURE SCREENS

Time in Hours	Temperature Range (R)								
	0.	10.	20.	30.	40.	50.	60.	70.	80.
10.	0.0124	0.0677	0.0991	0.1240	0.1452	0.1639	0.1809	0.1964	0.2108
20.	0.0247	0.1308	0.1885	0.2326	0.2693	0.3010	0.3290	0.3542	0.3772
30.	0.0368	0.1896	0.2689	0.3278	0.3754	0.4156	0.4504	0.4810	0.5084
40.	0.0488	0.2445	0.3414	0.4112	0.4661	0.5114	0.5498	0.5830	0.6121
50.	0.0606	0.2956	0.4067	0.4842	0.5436	0.5915	0.6312	0.6649	0.6938
60.	0.0723	0.3433	0.4655	0.5481	0.6099	0.6584	0.6979	0.7307	0.7584
70.	0.0839	0.3877	0.5185	0.6042	0.6665	0.7144	0.7525	0.7836	0.8093
80.	0.0953	0.4292	0.5663	0.6533	0.7149	0.7612	0.7973	0.8261	0.8495
90.	0.1065	0.4678	0.6093	0.6963	0.7563	0.8004	0.8339	0.8602	0.8812
100.	0.1176	0.5038	0.6480	0.7339	0.7917	0.8331	0.8640	0.8877	0.9063
110.	0.1286	0.5374	0.6829	0.7669	0.8219	0.8605	0.8886	0.9097	0.9260
120.	0.1394	0.5687	0.7144	0.7958	0.8478	0.8833	0.9087	0.9275	0.9416
130.	0.1501	0.5979	0.7427	0.8211	0.8699	0.9025	0.9252	0.9417	0.9539
140.	0.1607	0.6251	0.7682	0.8433	0.8888	0.9184	0.9388	0.9532	0.9636
150.	0.1711	0.6505	0.7912	0.8628	0.9049	0.9318	0.9498	0.9624	0.9713
160.	0.1814	0.6742	0.8119	0.8798	0.9187	0.9430	0.9589	0.9697	0.9774
170.	0.1916	0.6962	0.8305	0.8947	0.9305	0.9523	0.9663	0.9757	0.9821
180.	0.2017	.7168	0.8473	0.9077	0.9406	0.9602	0.9724	0.9805	0.9859
190.	0.2116	0.7360	0.8625	0.9192	0.9492	0.9667	0.9774	0.9843	0.9889
200.	0.2214	0.7538	0.8761	0.9292	0.9566	0.9721	0.9815	0.9874	0.9912
$\bar{\lambda}_f$	0.0013	0.0070	0.0104	0.0132	0.0157	0.0179	0.0199	0.0219	0.0237

2.3.5 Failure Rate of Defects in Stress Screens. The definition of screening strength is the probability that a screen will precipitate a defect, given that one is present. In the CDE model,

$$E(t) = \lambda_g t + D\left(1 - e^{-\bar{\lambda}_f t}\right)$$

$\lambda_g t$ is the failure rate of all the good parts, D is the number of defects and $\bar{\lambda}$ is the average failure rate of the defects. The term $e^{-\bar{\lambda}_f t}$ is the probability that a defect will survive time t and $(1-e^{-\bar{\lambda}_f t})$ is the probability that the defect will not survive (precipitate). Therefore, $(1-e^{-\bar{\lambda}_f t})$ is equivalent to the screening strength. Note in paragraph 2.3.3 that the form of the screening strength equation is

$$SS = (1 - e^{-xt})$$

except for temperature cycling in which the number of cycles is substituted for time, t. By substitution, x in the screening strength equations is an expression for determining the failure rate of defects $(\bar{\lambda}_f)$ under the stress screening conditions. For example, the screening strength of a random vibration screen of 6g-rms for 10 minutes can be calculated from equation (2-10) to be 0.627. Then,

$$0.627 = (1 - e^{-\bar{\lambda}_f t})$$

$$\bar{\lambda}_f = \frac{-\ln(1 - .627)}{10/60}$$

$$= 5.905 \text{ failures/hour}$$

The average failure rate of defects in a 6g-rms random vibration screen is 5.905 failures per hour.

Defect failure rates for stress screens are shown in Tables 2.18, 2.19, 2.21 and 2.22.

2.3.6 Probability of Detection. An important consideration in stress screening is the ability to detect defects precipitated (or manifested) by stress screens. There are three general types of defects, viz.,

Type 1. physical defects that transform from an inherent weakness to a hard failure,

Type 2. physical defects that manifest themselves as failures only while under thermal or mechanical stress, and

Type 3. functional defects that manifest themselves as performance failures (or anomalies) only while under thermal or mechanical stress.

It is believed by the author that the latter two types of defects comprise over 50 percent and occasionally as much as 80 percent of all defects present.

Type 1 defects precipitated by stress screens are detectable by post-screen tests. Type 2 defects are detectable only if performance is continuously monitored during stress screening (typically, intermittents). Type 3 defects also require continuous performance monitoring sufficiently thorough to detect subtle anomalies, e.g., timing (race problems), part parameter drift with temperature and tolerance build-up problems.

Printed wiring assemblies (PWA) are becoming more complex, defect rates are increasing and costs of PWA fault isolation and repair at end item test and during field use are 10-100 times that at the PWA level. This makes stress screening at the PWA level, and perhaps at the bare board level, more cost effective. Ref. 7 provides fault coverage (probability of detection) estimates for various automatic test systems commonly in use in today's factories and are shown in Table 2.23.

Ref. 7 also provides an illustration of fault coverage for a sample of 1000 PWAs subjected to various test strategies, as shown in Table 2.24. The strategies employed are the use of each of four automatic testers independently and in combination. It can be seen in the table that using only a FBT provides 95 percent fault coverage but combining ICT with FCB increases coverage to 97 percent and adding ICA to the sequence increases coverage to 99 percent. Abbreviations are defined in Table 2-23.

While the types of faults detected are typical manufacturing defects and do not cover the spectrum of defect types of interest in stress screening, the statistics provide a basis for developing estimates of probability of detection and should be helpful in selecting test strategies for stress screens.

2.4 Yield.

2.4.1 Definition of Yield. For the purposes of this study, the definition of yield is

"The probability that an equipment is free of defects when offered for acceptance"

TABLE 2.23. TYPICAL FAULT COVERAGE (P_D) FOR VARIOUS AUTOMATIC TEST SYSTEMS (REF. 7)

Circuit Type	Automatic Test System Type			
	Loaded Board Shorts Tester (LBS)	In-Circuit Analyzer (ICA)	In-Circuit Tester (ICT)	Functional Board Tester (FBT)
Digital	45% to 65%	50% to 75%	85% to 94%	90% to 98%
Analog	35% to 55%	70% to 92%	90% to 96%	80% to 90%
Hybrid	40% to 60%	60% to 90%	87% to 94%	83% to 95%

TABLE 2.24. FAULT DETECTION FOR A 1000 PCB LOT SIZE (REF. 7)

Fault Classification	Actual	LBS	ICA	ICT	FBT	ICA-ICT	ICA-FBT	ICT-FBT	ICA-ICT-FBT
Shorts	261	261	261	261	261	261	261	261	261
Opens	5	5	5	5	5	5	5	5	5
Missing Components	30		25	28	25	29	27	29	30
Wrong Components	67		53	61	55	64	59	60	65
Reversed Components	28		26	23	25	27	28	25	28
Bent Leads	43		38	43	43	43	43	43	43
Analog Specifications	25		13	21	18	21	21	22	23
Digital Logic	27			20	27	20	27	27	27
Performance	26				26		26	26	26
Total No. of Faults	512	266	421	462	486	470	497	498	508
Fault Coverage	100%	52%	82%	90%	95%	92%	97%	97%	99%
Fault Coverage Increase	-	-	-	-	-	2.2%	2.3%	2.5%	4.5%
Rejected PCBs	398	223	345	370	385	374	391	393	394
Rework Yield		195	316	354	376	361	384	388	393
Undetected Faulty PCB		203	82	44	22	37	14	10	5
Rework Yield		49%	79%	89%	94%	91%	96%	97%	99%
Rework Yield Increase	-	-	-	-	-	2%	2.1%	3.2%	4.5%
Finished Units		805	918	956	978	963	986	990	995

This definition is adopted for stress screening purposes for two reasons,

- It provides the procuring activity a means to specify, in a positive way, a level of acceptability of products which contain residual (unscreened) defects, and

- It allows the contractor to easily translate the yield requirement into a maximum number of allowable defects upon which to base a stress screening program.

If a production lot of units has an average number of defects per unit, say D, the probability that a given unit has zero defects (yield) is given by

$$P(0) = e^{-D}$$

So, if P(0) is specified, D can be determined by

$$D = -\ln P(0)$$

and D is the average number of defects per unit the contractor can have in his delivered products to meet the yield requirement. The contractor must then design an environmental stress screening (ESS) regimen that will eliminate defects such that his delivered average defects per unit does not exceed D.

2.4.2 Establishing a Yield Requirement. An acceptable yield is one which results from a program in which all cost-effective efforts have been made to eliminate defects and their sources. The number of defects introduced in manufacture of a product is dependent on four things:

- the quality level of parts procured
- manufacturing process controls
- ESS program effectiveness
- severity of use environment

The quality level of parts procured is usually established by the product mission, e.g.,

S - level quality for space programs
B - level quality for critical avionics
C - level quality for ground support equipment
D - level quality for commercial and industrial equipment

Manufacturing process controls vary with production quantity and complexity with controls being best for high volume low complexity products and least for low volume, high complexity products.

ESS programs that include tailored stress screens at various levels of assembly (part, module, unit, system) can be highly effective, approaching 0.95 in composite test strength. For example, let an ESS program be

distributed to three levels (say, modules, units, system) and each level has a conservative test strength of 0.60. The composite test strength is

$$TS_c = 1 - (1 - TS_1)(1 - TS_2)(1 - TS_3)$$

$$= 1 - .064$$

$$= .936$$

The use environment is fixed, based on the product mission, and will be one of the prescribed application environments in MIL-HDBK-217. The relationship between number of defects and environment is described in paragraph 2.2.5.

The required yield is determined by

$$\text{Yield} = e^{-D}$$

where D is the average defects remaining in the delivered item and is calculated by using the fraction defective tables (Tables 2.3 through 2.14) to estimate the total number of defects introduced and multiplying by 0.05 to account for 95 percent defect elimination through process control and stress screening prior to delivery. The following example illustrates the yield determination process.

An avionics equipment is to be procured with an upper test MTBF of 500 hours (Airborne Uninhabited Transport environment). Upon design of the equipment during the design and development phase, the contractor determines the quantity of parts by type and estimates the number of defects using the fraction defective tables, (See Table 2.25), which is 2.739 defects per each unit produced. This value is multiplied by 0.05 to give 0.137, which represents the average outgoing defects per unit. Yield is then calculated by

$$\text{Yield} = e^{-.137}$$
$$= .87$$

An attempt was made to determine if yield could be determined solely on the basis of specified MTBF. First, a "typical" system was defined as containing 10,000 parts distributed as follows:

microelectronic devices	2900
discrete semiconductors	1000
passive parts	5500
other parts	600
	10,000

TABLE 2.25. DEFECT ESTIMATION EXAMPLE

Part Type	Quantity	Qual. Level	Fraction Defective*	Estimated Defects
Microelectronic Devices	1811	B-1	159.4	.289
Transistors	279	JTX	258.6	.072
Diodes	612	JTX	65.4	.004
Resistors	1827	M	44.0	.080
Capacitors	2166	M	307.5	.666
Inductive Devices	96	Mil	1339.6	.129
Rotating Devices	5	-	18051.9	.090
Relays	37	Mil	689.6	.026
Switches	53	Mil	6.5	negl.
Connectors	172	Mil	403.6	.069
Printed Wiring Boards	110	Mil	3282.3	.361
Connections, Hand Solder	12,500	-	74.0	.925
Connections, Crimp (Manual, Upper)	1,500		7.4	.011
Connections, Weld				
Connections, Solderless Wrap	32,500		0.1	.003
Connections, Wrapped and Soldered				
Connections, Clip Termination				
Connections, Reflow Solder	7,000		2.0	.014
			Total	2.739

*per 10^6

This distribution of parts is based on the parts mix of 16 diverse equipments (Ref. 1, Table 4.4, p. 74). Failure rates were calculated for the parts using MIL-HDBK-217 for each application environment (see Table 2.26) and the estimated number of defectives was determined from the fraction defective tables. Yield was calculated on the basis of 95 percent defect removal and results were plotted versus MTBF (Fig. 2.5). The best fit, using standard non-linear regression techniques, is

$$\text{Yield} = 1 - \frac{1}{\left[1 + \left(\frac{\text{MTBF}}{493}\right)^{1.42}\right]}$$

The function is tabled in Table 2.27

2.4.3 <u>Verifying Yield</u>. Actual yield can be verified by conducting a failure-free test of a predetermined length depending on the yield requirement, the lower confidence bound on the yield verification and the degree of stress applied to the equipment during the failure free test. The method of calculating the lower confidence bounds is described below.

The Verified Yield is defined as the conditional probability of having no defects given that no defects are detected in a test of length T. It follows from Ref. 5 using the chance-defective exponential model that the Yield is given by:

$$\text{Yield} = \exp\left(-D \exp\left(-\bar{\lambda}_f T\right)\right),$$

where D is the average number of defects in an item produced, and $\bar{\lambda}_f$ is the defect failure rate. A lower confidence bound on Yield based on surviving a failure-free period of length T can be computed by calculating an upper confidence bound on D*. Following Brownlee (Ref. 9) this is accomplished by solving

$$\exp\left(- N\, \bar{\lambda}_g T - D^* \left(1-\exp\left(- \bar{\lambda}_f T\right)\right)\right) = 1 - \text{CONF}$$

for D*. The left hand side above is the probability of surviving T according to the chance-defective exponential model, $N\bar{\lambda}_g$ is the failure rate of all the good parts, and CONF is the desired confidence level. The value of D* is thus

$$D^* = \frac{\ln\left(1/(1-\text{CONF})\right) - \bar{\lambda}_f T/(\bar{\lambda}_f/N\bar{\lambda}_g)}{1-\exp\left(-\bar{\lambda}_f T\right)}$$

The upper confidence limit on D is then

$$\bar{D} = \text{Max}\,(0,\ D^*)$$

TABLE 2.26. CALCULATED FAILURE RATES AND MTBF FOR A TYPICAL SYSTEM IN VARIOUS APPLICATION ENVIRONMENTS

ENV.	IC (2900)	SC (1000)	R,C (5500)	CONN. (600)	$\Sigma\lambda$	$\frac{\lambda}{\lambda_{GF}}$	SAMPLE MTBF
GB	.015	.0025	.0036	.0056			
	43.5	2.5	19.8	3.36	69.16	0.29	3448
GF	.062	.016	.0059	.017			
	179.8	16.0	32.45	10.2	238.45	1.0	1000
GM	.108	.062	.030	.250			
	313.2	62.0	165.0	150.0	690.2	2.89	346
MP	.087	.031	.041	.160			
	252.3	31.0	225.5	96.0	604.8	2.54	394
NSB	.093	.026	.019	.057			
	269.7	26.0	104.5	34.2	434.4	1.82	549
NS	.093	.026	.020	.074			
	269.7	26.0	110.0	44.4	450.1	1.89	529
NU	.168	.098	.050	.400			
	487.2	98.0	275.0	240.0	1100.2	4.61	217
NH	.135	.051	.059	.180			
	391.5	51.0	324.5	108.0	875.0	3.67	272
NUU	.135	.043	.063	.170			
	391.5	43.0	346.5	102.0	883.0	3.70	270
ARW	.198	.092	.094	.560			
	574.2	92.0	517.0	336.0	1519.2	6.37	157
AIT	.093	.041	.033	.150			
	269.7	41.0	181.5	90.0	582.2	2.44	410
AIF	.168	.086	.066	.300			
	487.2	86.0	363.0	180.0	1116.2	4.68	214
AUT	.105	.091	.068	.210			
	304.5	91.0	374.0	126.0	895.5	3.76	266
AUF	.189	.180	.140	.430			
	548.1	180.0	770.0	258.0	1756.1	7.36	136
SF	.024	.001	.0029	.0056			
	69.6	1.0	15.95	3.36	89.91	0.38	2632
MFF	.096	.036	.042	.099			
	278.4	36.0	231.0	59.4	604.8	2.54	394
MFA	.126	.050	.057	.140			
	365.4	50.0	313.5	84.0	812.9	3.41	293
USL	.240	.094	.120	.230			
	696.0	94.0	660.0	138.0	1588.0	6.66	150
ML	.294	.140	.140	.430			
	852.6	140.0	770.0	258.0	2020.6	8.47	118

Note: Failure Rates are in $f/10^6$ hrs.

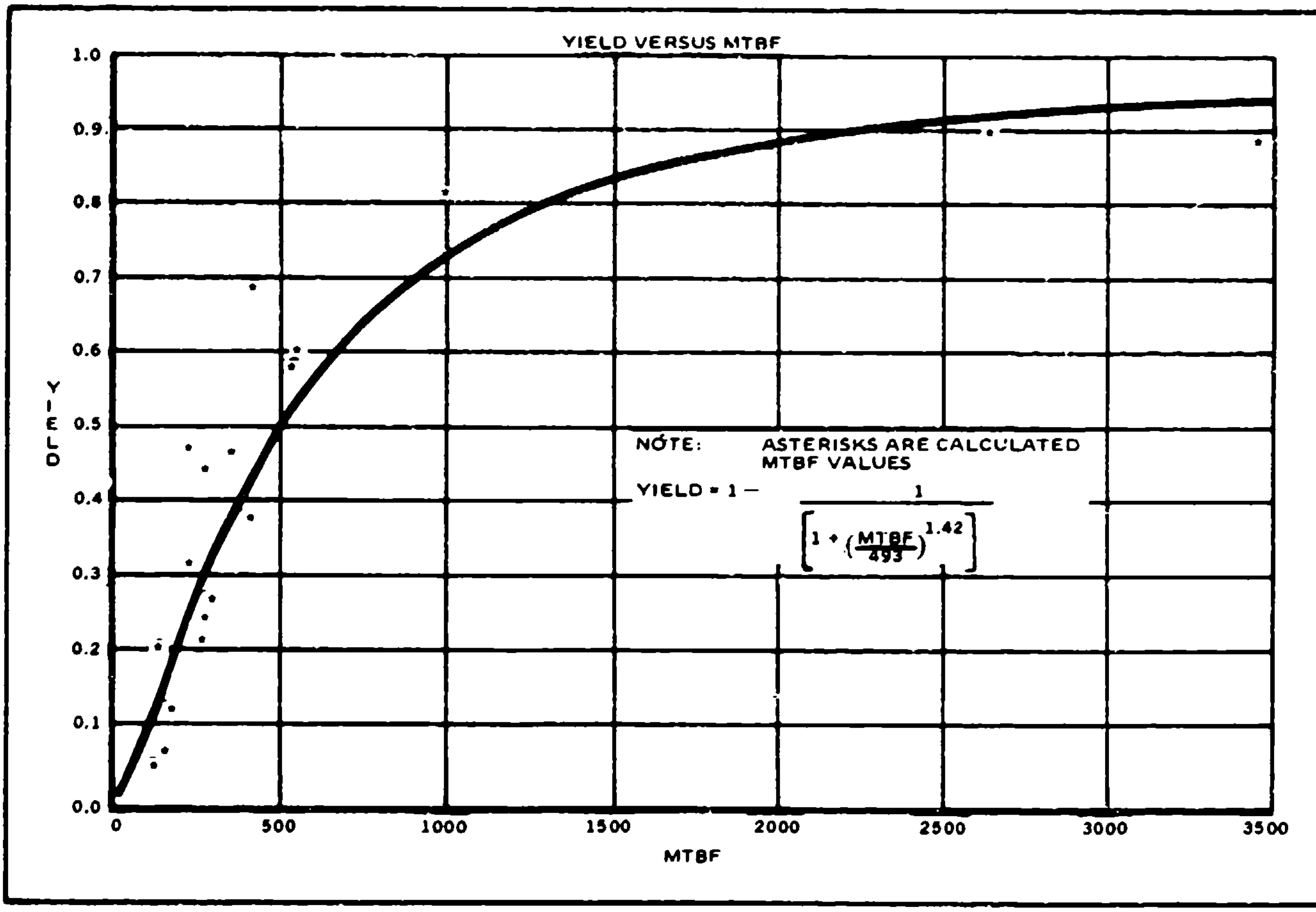

Figure 2.5. Yield versus MTBF

TABLE 2.27. YIELD VALUES CORRESPONDING TO SPECIFIED MTBF

MTBF	YIELD	MTBF	YIELD	MTBF	YIELD
100	.09	1850	.87	3600	.94
150	.16	1900	.87		
200	.22	1950	.88	3800	.95
250	.28	2000	.88		
300	.33	2050	.88	4000	.95
350	.38	2100	.89		
400	.43	2150	.89	4200	.95
450	.48	2200	.89	4400	.96
500	.51	2250	.90	4600	.96
550	.54	2300	.90	4800	.96
600	.57	2350	.90	5000	.96
650	.60	2400	.90	6000	.97
700	.62	2450	.91	7000	.98
750	.64	2500	.91	8000	.98
800	.67			9000	.98
850	.68	2600	.91	10,000	.99
900	.70			20,000	.995
950	.72	2700	.92	30,000	.997
1000	.73			40,000	.998
1050	.75	2800	.92	50,000	.9985
1100	.76			60,000	.999
1150	.77	2900	.93	70,000	.9991
1200	.78			80,000	.9993
1250	.79	3000	.93	90,000	.9994
1300	.80			100,000	.9995
1350	.81	3100	.93		
1400	.81				
1450	.82	3200	.93		
1500	.83				
1550	.84	3300	.94		
1600	.84				
1650	.85	3400	.94		
1700	.85				
1750	.86	3500	.94		
1800	.86				

and the lower confidence bound on Yield is given by

$$\exp\,(-D \exp\,(-\,\bar{\lambda}_f T)). \qquad (2\text{-}16)$$

Note that this expression depends only on $\bar{\lambda}_f T$ and the ratio $\bar{\lambda}_f/N\bar{\lambda}g$. Lower confidence bound tables for 90, 80, 70, 60 and 50 percent are provided as Tables 2.28 through 2.37.

2.4.4 Example of Determining the Failure Free Period from Yield. Tables 2.28 through 2.37 can be used to determine the required failure-free period for yield values and 50 percent to 90 percent lower confidence bounds on yield. Use of the tables is illustrated in the following example.

Find the failure-free period that will verify a yield of 0.90 with a 70 percent lower confidence bound. Two values are needed, viz.,

1. The failure rate of all good parts ($N\bar{\lambda}g$). This can be estimated by using the reciprocal of the predicted or specified MTBF.

2. The failure rate of the defects ($\bar{\lambda}_f$). This can be found in the screening strength table (Table 2.18 through 2.22).

Assume the predicted MTBF is 1000 hours. Then $N\bar{\lambda}g$ is 0.001. Let the failure-free test be conducted under constant temperature conditions of 55°C. From Table 2.22 (R=30), $\bar{\lambda}_f = .0132$. Divide $\bar{\lambda}_f/N\bar{\lambda}_g$ (.0132/.001) to get 13.2. This is the column to enter in Table 2.32. (Use column 10.00.)

Proceed down the column to the yield value of 0.90 (interpolate between 0.89 and 0.91). Read across to the leftmost column (2.3). This value is $\bar{\lambda}_f \cdot T$, so to solve for T (failure-free period),

$$\begin{aligned}\bar{\lambda}_f T &= 2.3\\ T &= 2.3/\bar{\lambda}_f\\ &= 2.3/.0123\\ &= 187 \text{ hours}\end{aligned}$$

This states that to verify a .90 yield with a 70 percent lower confidence bound, the product must operate for 187 hours failure free at 55°C. To shorten the time, the $\bar{\lambda}_f$ value must increase, requiring a more severe operating environment.

TABLE 2.28. 90 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

$(\bar{\lambda}_f T)$	Failure Rate Ratio $(\bar{\lambda}_f/N\bar{\lambda}_g)$												
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.47	0.35	0.32	0.30	0.29	0.29	0.28	0.28	0.28	0.28	0.27	0.27	0.26
1.1	0.55	0.42	0.38	0.36	0.35	0.35	0.34	0.34	0.34	0.33	0.33	0.32	0.32
1.2	0.62	0.48	0.44	0.42	0.41	0.40	0.40	0.40	0.39	0.39	0.38	0.38	0.37
1.3	0.69	0.54	0.50	0.48	0.47	0.46	0.45	0.45	0.45	0.44	0.43	0.43	0.43
1.4	0.74	0.59	0.55	0.53	0.52	0.51	0.50	0.50	0.50	0.49	0.48	0.48	0.47
1.5	0.79	0.64	0.60	0.57	0.56	0.55	0.55	0.54	0.54	0.54	0.53	0.52	0.52
1.6	0.84	0.68	0.64	0.62	0.61	0.60	0.59	0.59	0.58	0.58	0.57	0.56	0.56
1.7	0.87	0.72	0.68	0.66	0.64	0.64	0.63	0.63	0.62	0.62	0.61	0.60	0.60
1.8	0.91	0.76	0.71	0.69	0.68	0.67	0.67	0.66	0.66	0.66	0.65	0.64	0.64
1.9	0.93	0.79	0.75	0.73	0.71	0.71	0.70	0.70	0.69	0.69	0.68	0.67	0.67
2.0	0.95	0.82	0.77	0.75	0.74	0.73	0.73	0.73	0.72	0.72	0.71	0.70	0.70
2.2	0.99	0.86	0.82	0.80	0.79	0.79	0.78	0.78	0.77	0.77	0.76	0.76	0.75
2.4	1.00	0.90	0.86	0.84	0.83	0.83	0.82	0.82	0.82	0.81	0.80	0.80	0.80
2.6	1.00	0.92	0.89	0.88	0.87	0.86	0.86	0.85	0.85	0.85	0.84	0.84	0.83
2.8	1.00	0.94	0.92	0.90	0.89	0.88	0.88	0.88	0.88	0.87	0.87	0.87	0.86
3.0	1.00	0.96	0.93	0.92	0.91	0.91	0.91	0.90	0.90	0.90	0.89	0.89	0.89
3.5	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.94	0.94	0.94	0.93	0.93
4.0	1.00	0.99	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.96
5.0	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 2.29. 90 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio ($\bar{\lambda}_f/N\bar{\lambda}_g$)									
($\bar{\lambda}_f T$)	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3	1.00	0.10	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
0.4	1.00	0.54	0.14	0.07	0.05	0.04	0.03	0.03	0.02	0.02
0.5	1.00	1.00	0.38	0.20	0.13	0.10	0.09	0.08	0.07	0.06
0.6	1.00	1.00	0.69	0.38	0.26	0.21	0.17	0.15	0.14	0.13
0.7	1.00	1.00	1.00	0.58	0.41	0.33	0.28	0.24	0.22	0.21
0.8	1.00	1.00	1.00	0.78	0.56	0.45	0.39	0.35	0.32	0.29
0.9	1.00	1.00	1.00	0.96	0.71	0.58	0.50	0.45	0.41	0.38
1.0	1.00	1.00	1.00	1.00	0.84	0.69	0.60	0.54	0.50	0.47
1.1	1.00	1.00	1.00	1.00	0.95	0.79	0.69	0.63	0.58	0.55
1.2	1.00	1.00	1.00	1.00	1.00	0.88	0.78	0.71	0.66	0.62
1.3	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.78	0.73	0.69
1.4	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.83	0.78	0.74
1.5	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.88	0.83	0.79
1.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.88	0.84
1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.91	0.87
1.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.94	0.91
1.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.93
2.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95

TABLE 2.30. 80 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

	Failure Rate Ratio ($\bar{\lambda}_f/N\bar{\lambda}_g$)												
($\bar{\lambda}_f T$)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.70	0.52	0.48	0.45	0.44	0.43	0.43	0.42	0.42	0.42	0.40	0.40	0.40
1.1	0.78	0.59	0.54	0.51	0.50	0.49	0.48	0.48	0.48	0.47	0.46	0.45	0.45
1.2	0.84	0.65	0.59	0.57	0.55	0.54	0.54	0.53	0.53	0.53	0.51	0.51	0.50
1.3	0.89	0.70	0.64	0.62	0.60	0.59	0.59	0.58	0.58	0.57	0.56	0.55	0.55
1.4	0.93	0.74	0.69	0.66	0.65	0.64	0.63	0.63	0.62	0.62	0.60	0.60	0.60
1.5	0.97	0.76	0.73	0.70	0.69	0.68	0.67	0.66	0.66	0.66	0.64	0.64	0.63
1.6	1.00	0.81	0.76	0.74	0.72	0.71	0.71	0.70	0.70	0.69	0.68	0.67	0.67
1.7	1.00	0.84	0.79	0.77	0.75	0.74	0.74	0.73	0.73	0.72	0.72	0.71	0.71
1.8	1.00	0.87	0.82	0.79	0.78	0.77	0.77	0.76	0.76	0.75	0.74	0.73	0.73
1.9	1.00	0.89	0.84	0.82	0.81	0.80	0.79	0.79	0.78	0.78	0.77	0.76	0.76
2.0	1.00	0.91	0.86	0.84	0.83	0.82	0.81	0.81	0.80	0.80	0.79	0.78	0.78
2.2	1.00	0.94	0.90	0.88	0.86	0.86	0.85	0.85	0.84	0.84	0.83	0.83	0.82
2.4	1.00	0.96	0.92	0.90	0.89	0.89	0.88	0.88	0.87	0.87	0.86	0.86	0.86
2.6	1.00	0.98	0.94	0.93	0.92	0.91	0.91	0.90	0.90	0.90	0.89	0.88	0.88
2.8	1.00	0.99	0.96	0.94	0.93	0.93	0.92	0.92	0.92	0.92	0.91	0.91	0.90
3.0	1.00	0.99	0.97	0.96	0.95	0.94	0.94	0.94	0.94	0.93	0.93	0.92	0.92
3.5	1.00	1.00	0.99	0.98	0.97	0.97	0.97	0.96	0.96	0.96	0.96	0.95	0.95
4.0	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97
5.0	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 2.31. 80 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio, $(\bar{\lambda}_f/N\bar{\lambda}_g)$									
$(\bar{\lambda}_f T)$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	0.06	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.3	1.00	0.73	0.18	0.09	0.06	0.04	0.03	0.03	0.03	0.02
0.4	1.00	1.00	0.57	0.29	0.19	0.15	0.12	0.10	0.09	0.09
0.5	1.00	1.00	1.00	0.57	0.39	0.30	0.25	0.22	0.20	0.18
0.6	1.00	1.00	1.00	0.88	0.61	0.48	0.40	0.35	0.32	0.29
0.7	1.00	1.00	1.00	1.00	0.81	0.65	0.55	0.48	0.44	0.41
0.8	1.00	1.00	1.00	1.00	0.99	0.80	0.68	0.61	0.56	0.52
0.9	1.00	1.00	1.00	1.00	1.00	0.93	0.80	0.72	0.66	0.62
1.0	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.81	0.75	0.70
1.1	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.89	0.82	0.78
1.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.89	0.84
1.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.89
1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.93
1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97

TABLE 2.32. 70 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

$(\bar{\lambda}_f T)$	Failure Rate Ratio $(\bar{\lambda}_f/N\bar{\lambda}_g)$												
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.89	0.66	0.60	0.57	0.56	0.55	0.54	0.53	0.53	0.53	0.51	0.50	0.50
1.1	0.95	0.72	0.66	0.63	0.61	0.60	0.59	0.59	0.58	0.58	0.56	0.56	0.55
1.2	1.00	0.77	0.71	0.68	0.66	0.65	0.64	0.63	0.63	0.63	0.61	0.60	0.60
1.3	1.00	0.81	0.75	0.72	0.70	0.69	0.68	0.68	0.67	0.67	0.65	0.64	0.64
1.4	1.00	0.85	0.79	0.76	0.74	0.73	0.72	0.71	0.71	0.71	0.69	0.68	0.68
1.5	1.00	0.88	0.82	0.79	0.77	0.76	0.75	0.75	0.74	0.74	0.72	0.72	0.71
1.6	1.00	0.90	0.84	0.82	0.80	0.79	0.78	0.78	0.77	0.77	0.75	0.74	0.74
1.7	1.00	0.92	0.87	0.84	0.82	0.81	0.81	0.80	0.80	0.79	0.78	0.77	0.77
1.8	1.00	0.94	0.89	0.86	0.85	0.84	0.83	0.82	0.82	0.82	0.80	0.79	0.79
1.9	1.00	0.96	0.90	0.88	0.87	0.86	0.85	0.84	0.84	0.84	0.82	0.82	0.81
2.0	1.00	0.97	0.92	0.90	0.88	0.87	0.87	0.86	0.86	0.85	0.84	0.83	0.83
2.2	1.00	0.99	0.94	0.92	0.91	0.90	0.90	0.90	0.89	0.89	0.88	0.87	0.86
2.4	1.00	1.00	0.96	0.94	0.93	0.92	0.92	0.91	0.91	0.91	0.90	0.89	0.89
2.6	1.00	1.00	0.97	0.96	0.95	0.94	0.94	0.93	0.93	0.93	0.92	0.91	0.91
2.8	1.00	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.94	0.93	0.93	0.93
3.0	1.00	1.00	0.99	0.98	0.97	0.96	0.96	0.96	0.96	0.95	0.95	0.94	0.94
3.5	1.00	1.00	1.00	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.96
4.0	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 2.33. 70 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

$\bar{\lambda}_f T$	Failure Rate Ratio $(\bar{\lambda}f/N\bar{\lambda}_g)$									
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	0.40	0.09	0.04	0.03	0.02	0.02	0.01	0.01	0.01
0.3	1.00	1.00	0.56	0.27	0.18	0.13	0.11	0.09	0.08	0.08
0.4	1.00	1.00	1.00	0.66	0.44	0.34	0.28	0.24	0.21	0.20
0.5	1.00	1.00	1.00	1.00	0.73	0.56	0.47	0.41	0.37	0.34
0.6	1.00	1.00	1.00	1.00	1.00	0.78	0.66	0.58	0.52	0.48
0.7	1.00	1.00	1.00	1.00	1.00	0.96	0.82	0.72	0.66	0.61
0.8	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.77	0.72
0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.87	0.81
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.89
1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95

TABLE 2.34. 60 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

	Failure Rate Ratio ($\bar{\lambda}_f/N\bar{\lambda}_g$)												
($\bar{\lambda}_f T$)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	1.00	0.78	0.71	0.68	0.66	0.65	0.64	0.63	0.63	0.62	0.60	0.60	0.59
1.1	1.00	0.83	0.76	0.73	0.71	0.69	0.68	0.68	0.67	0.67	0.65	0.64	0.64
1.2	1.00	0.87	0.80	0.77	0.75	0.73	0.73	0.72	0.71	0.71	0.69	0.68	0.68
1.3	1.00	0.91	0.83	0.80	0.78	0.77	0.76	0.75	0.75	0.74	0.73	0.72	0.72
1.4	1.00	0.93	0.86	0.83	0.81	0.80	0.79	0.78	0.78	0.78	0.76	0.75	0.75
1.5	1.00	0.95	0.89	0.86	0.84	0.83	0.82	0.81	0.81	0.80	0.79	0.78	0.77
1.6	1.00	0.97	0.91	0.88	0.86	0.85	0.84	0.83	0.83	0.83	0.81	0.80	0.80
1.7	1.00	0.99	0.92	0.90	0.88	0.87	0.86	0.85	0.85	0.85	0.83	0.82	0.82
1.8	1.00	1.00	0.94	0.91	0.90	0.89	0.88	0.87	0.87	0.86	0.85	0.84	0.84
1.9	1.00	1.00	0.95	0.93	0.91	0.90	0.89	0.89	0.88	0.88	0.87	0.86	0.86
2.0	1.00	1.00	0.96	0.94	0.92	0.91	0.91	0.90	0.90	0.89	0.88	0.87	0.87
2.2	1.00	1.00	0.98	0.96	0.94	0.93	0.93	0.93	0.92	0.92	0.90	0.90	0.90
2.4	1.00	1.00	0.99	0.97	0.96	0.95	0.94	0.94	0.94	0.93	0.92	0.92	0.92
2.6	1.00	1.00	1.00	0.98	0.97	0.96	0.96	0.95	0.95	0.95	0.94	0.93	0.93
2.8	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.95	0.95	0.95
3.0	1.00	1.00	1.00	0.99	0.98	0.98	0.97	0.97	0.97	0.97	0.96	0.96	0.96
3.5	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97
4.0	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 2.35. 60 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio ($\bar{\lambda}_f/N\bar{\lambda}_g$)									
$\bar{\lambda}_f T$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	1.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	1.00	0.32	0.15	0.10	0.07	0.06	0.05	0.04	0.04
0.3	1.00	1.00	1.00	0.62	0.40	0.30	0.25	0.21	0.19	0.17
0.4	1.00	1.00	1.00	1.00	0.79	0.60	0.50	0.43	0.38	0.35
0.5	1.00	1.00	1.00	1.00	1.00	0.88	0.73	0.64	0.57	0.53
0.6	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.82	0.74	0.68
0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.87	0.81
0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.91
0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99

TABLE 2.36. 50 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

	Failure Rate Ratio ($\bar{\lambda}f/N\bar{\lambda}_g$)												
($\bar{\lambda}_f T$)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	1.00	0.89	0.81	0.77	0.75	0.74	0.73	0.72	0.71	0.71	0.69	0.68	0.67
1.1	1.00	0.93	0.85	0.81	0.79	0.78	0.77	0.76	0.75	0.75	0.73	0.72	0.71
1.2	1.00	0.96	0.88	0.84	0.82	0.81	0.80	0.79	0.79	0.78	0.76	0.75	0.75
1.3	1.00	0.98	0.91	0.87	0.85	0.84	0.83	0.82	0.81	0.81	0.79	0.78	0.78
1.4	1.00	1.00	0.93	0.89	0.87	0.86	0.85	0.84	0.84	0.83	0.82	0.81	0.80
1.5	1.00	1.00	0.95	0.91	0.89	0.88	0.87	0.86	0.86	0.86	0.84	0.83	0.83
1.6	1.00	1.00	0.96	0.93	0.91	0.90	0.89	0.88	0.88	0.87	0.86	0.85	0.84
1.7	1.00	1.00	0.97	0.94	0.92	0.91	0.90	0.90	0.89	0.89	0.87	0.86	0.86
1.8	1.00	1.00	0.98	0.95	0.94	0.93	0.92	0.91	0.91	0.90	0.89	0.88	0.88
1.9	1.00	1.00	0.99	0.96	0.95	0.94	0.93	0.92	0.92	0.92	0.90	0.89	0.89
2.0	1.00	1.00	1.00	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.91	0.90	0.90
2.2	1.00	1.00	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.93	0.92	0.92
2.4	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.94	0.94	0.94
2.6	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.96	0.95	0.95
2.8	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.96	0.96	0.96
3.0	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97
3.5	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98
4.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 2.37. 50 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio ($\bar{\lambda}f/N\bar{\lambda}_g$)									
$\bar{\lambda}_f T$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	1.00	0.16	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00
0.2	1.00	1.00	0.89	0.42	0.27	0.20	0.16	0.14	0.12	0.11
0.3	1.00	1.00	1.00	1.00	0.77	0.58	0.47	0.40	0.36	0.33
0.4	1.00	1.00	1.00	1.00	1.00	0.95	0.78	0.68	0.60	0.55
0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.81	0.74
0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.89

3.0 DRAFT MILITARY STANDARD

3.1 Purpose of the Military Standard. A draft military standard on environmental stress screening is one of the products of this study. The purpose of the military standard is to provide uniform procedures, methods and guidelines for planning, monitoring and controlling the cost effectiveness of stress screening programs for military electronic equipment. It is intended to satisfy the requirements of MIL-STD-785B, Reliability Program for Systems and Equipment Development and Production, Task 301, Environmental Stress Screening.

3.2 Organization of the Military Standard. The draft military standard is organized according to the general sequence of events to be undertaken by contractors doing the stress screening (see Figure 3.1). The product development phase is used to plan for and experiment with various stress screens to determine which are most effective for the particular equipment being screened. As a result of the development phase activities, a specific stress screening regimen is defined for the production.

3.3 Development Phase ESS Planning Requirements.

3.3.1 Estimating the Number of Defects. The quantitative approach to stress screening planning and control is based on the premise that it is possible to estimate, in advance of product manufacture, the quantity and types of defects expected to be present in the product. Defect estimation is analogous to failure rate estimation using the failure rate models of MIL-HDBK-217. The future development of a data base of the observed defects escaping product manufacture will enable the development of models similar to those in MIL-HDBK-217 for more accurate estimation. Until then, contractors must use their own in-house data or the defect estimation tables in the stress screening military standard. The methodology for defect estimation is defined in the draft military standard, Appendix A, paragraph 5.1.1. Following is an example of defective estimation for a typical military electronics product.

3.3.1.1 System Breakdown. The system to be stress screened is a Communications System comprised of nine Units, as shown in Figure 3.2. Each of the Units is then further defined to the assembly level as shown in Figure 3.3. Only the Processor Unit breakdown is shown in this example. The printed wiring assemblies (PWA) are shown in Table 3.1. Figure 3.4 shows the estimate of the number of defects for one of the assemblies in Table 3.1. A Defect Estimation Worksheet is needed for each assembly in the Communications System. For large systems, manually estimating the number of defects is a laborious process. However, the process can be readily automated if the system indentured configuration is available in a computerized data base.

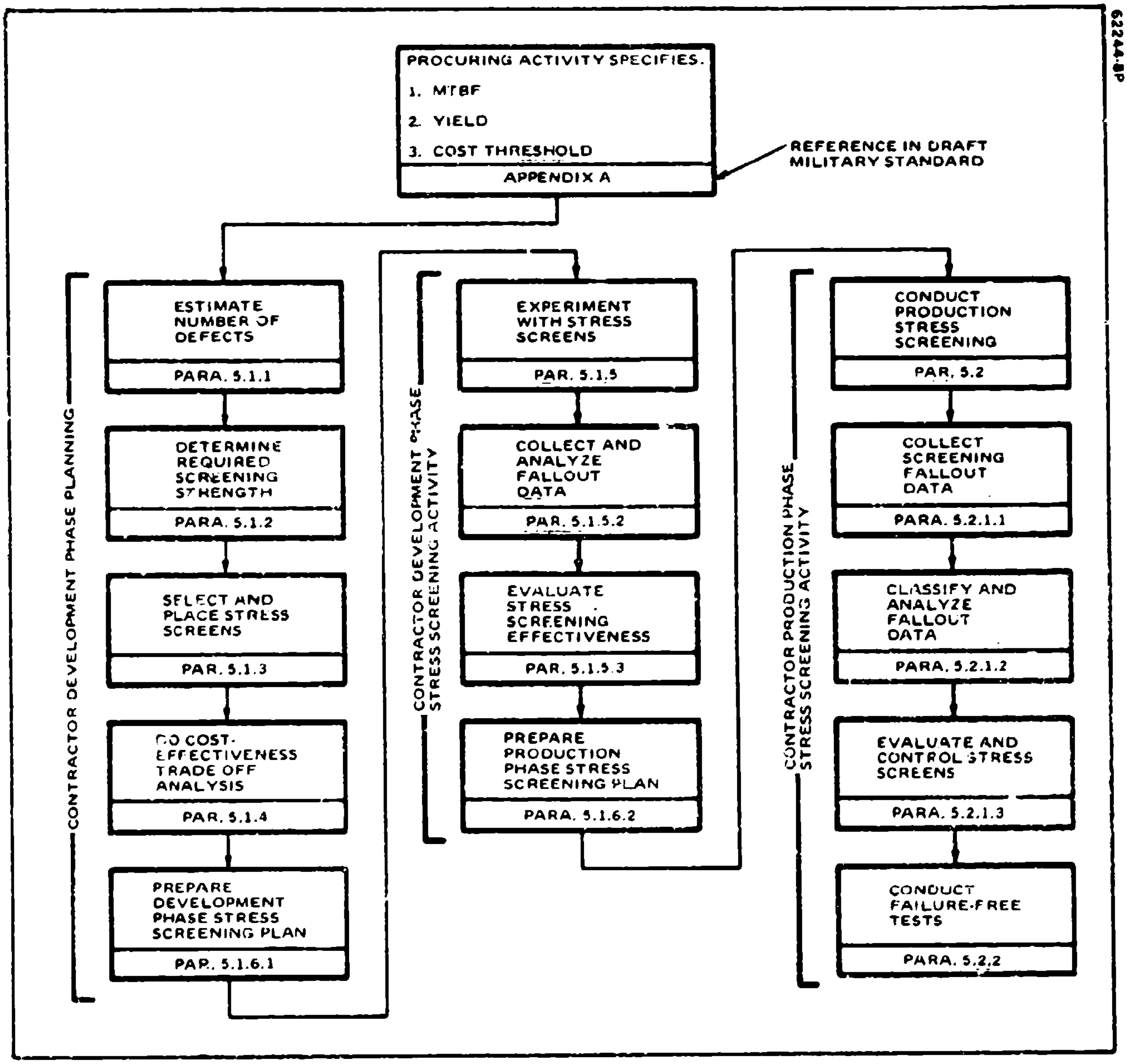

Figure 3.1. Sequence of Events in Planning, Monitoring and Controlling a Stress Screening Program

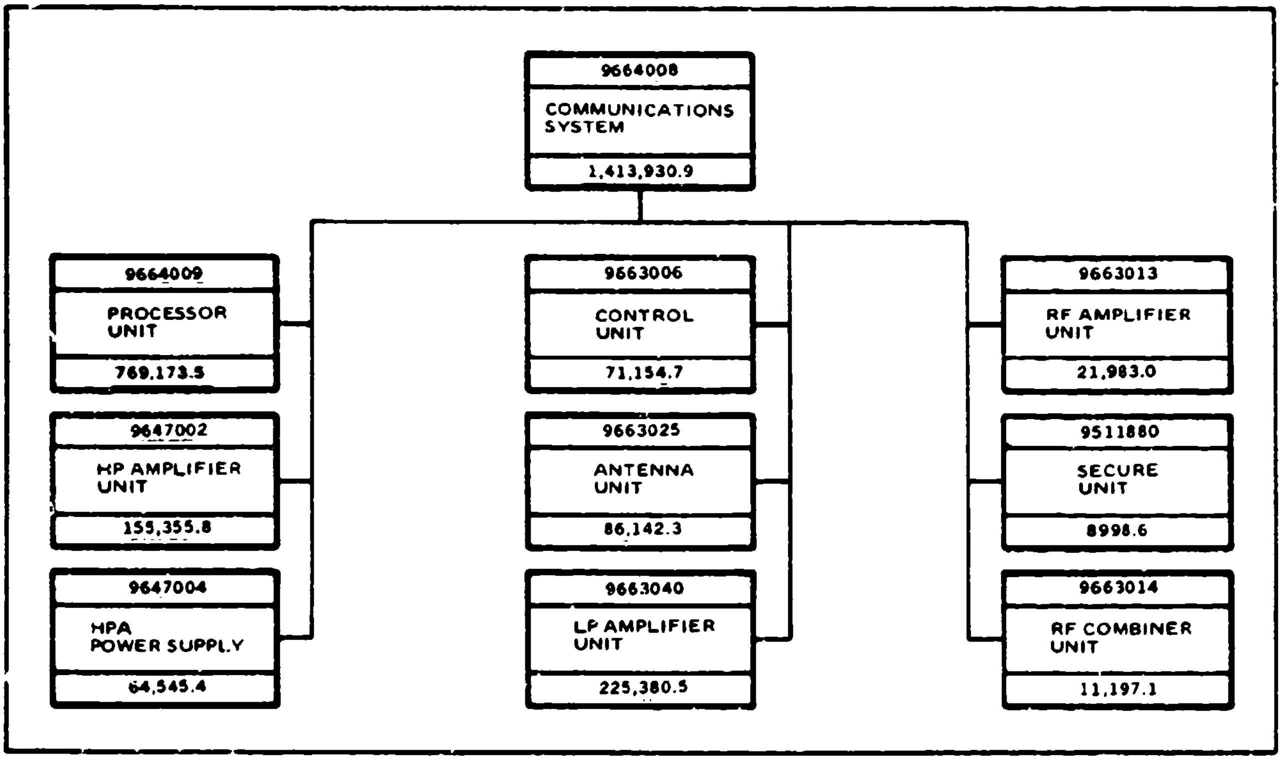

Figure 3.2. System Breakdown Chart for a Communications System

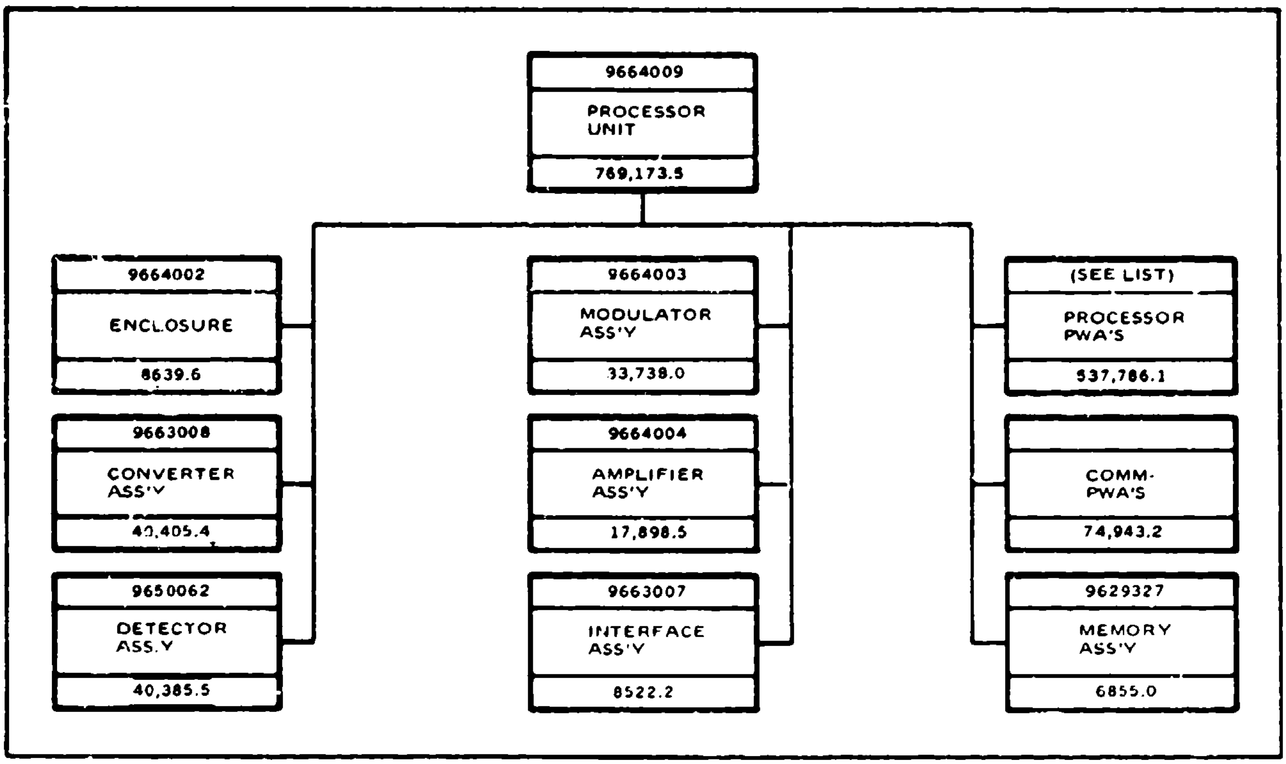

Figure 3.3. Processor Unit Breakdown to the Assembly Level

TABLE 3.1. LIST OF PROCESSOR UNIT PWAs

Qty	Part Number	Nomenclature	Estimated Defects*
1	9664060	Sequencer Assembly	13,771.8
1	9664061	Timing Assembly -1	21,256.2
1	9664062	Timing Assembly -2	19,829.0
1	9664063	Event Sequencer Assembly	13,864.4
1	9664064	Timing Control Assembly	12,990.2
1	9664065	Interleave Assembly	22,791.6
1	9664066	Interleave Timing Assembly	11,446.8
1	9664067	Delay Assembly -A	26,098.2
1	9664068	Demodulator Assembly	60,096.5
1	9664069	Tracker Assembly	5,328.6
1	9664070	Delay Assembly -B	20,811.0
1	9664071	Input Buffer Assembly	25,174.6
1	9664072	Output Buffer Assembly	17,298.8
1	9664073	Formatter Assembly	21,785.9
1	9664074	Interface Assembly -1	6,160.9
1	9664075	Clock Control Assembly	20,371.8
4	9664076	Correlator Assembly	50,998.4
1	9664077	Arithmetic/Memory Assembly	14,083.4
1	9664078	Address Select Assembly	25,234.4
1	9664079	Interface Assembly -2	4,395.4
1	9664080	Timing Assembly -3	2,117.0
1	9664081	Detector Assembly	33,008.3
1	9664082	Frequency Selector Assembly	5,083.2
1	9664083	Interface Assembly -3	16,379.1
1	9664084	Fault Isolation Assembly	13,842.4
1	9664085	Frequency Control Assembly	5,327.2
1	9664086	Timing Assembly -4	20,921.0
1	9664087	Quantizer Assembly	24,216.6
1	9664088	Arithmetic Assembly	2,662.8
		*per10^6 Total	537,786.1

DEFECT ESTIMATION WORKSHEET

Program/Project	System Nomenclature	Envir.
Communications Distribution Program	Communications System 9664008	AIT

Unit	Assembly	Prepared by	Date
Processor Unit 9664009	Interface Assy-1 9664074	A.E. Saari	3/21/85

Part Type	Quality Level	Qty	Fraction Defective	Estimated Defects*
Microelectronic	B-0	49	87.0	4263.0
Transistors				
Diodes	JANTX	1	46.9	46.9
Resistors	ER-M	18	23.8	428.4
Capacitors	ER-M	1	115.3	115.3
Inductive Devices				
Rotating Devices				
Relays				
Switches				
Connectors	M/S	1	168.0	168.0
Printed Wiring Boards	M/S	1	1139.3	1139.3
Connections, Hand Solder				
Connections, Crimp				
Connections, Weld				
Connections, Solderless Wrap				
Connections, Wrapped and Soldered				
Connections, Clip Termination				
Connections, Reflow Solder				
* per 10^6				6160.9

FIGURE 3.4. COMPLETED WORKSHEET FOR A SAMPLE ASSEMBLY

After all Defect Estimation Worksheets are completed, assembly totals are entered on the Unit Breakdown Charts (Figure 3.3) and Unit totals are entered onto the System Breakdown Chart (Figure 3.2). In this example, it is estimated that each system produced will have approximately 1.414 defects.

3.3.2 Determining Required Test Strength. Test strength is the product of the probability of a stress screen precipitating a defect into a detectable failure (screening strength) and the probability that the operational and functional tests of the item being screened will detect the failure (test detection efficiency).

3.3.2.1 Determine Required Screening Strength. In this example, the customer has specified a required Yield of 0.75, i.e., each product delivered has a 75 percent probability of being free of defects. It can be reasonably assumed that the remaining defects are uniformly distributed across all systems produced, having an average number of defects, D. Using the Poission approximation for the probability of zero defects, given a mean number of D,

$$P(0) = e^{-D} = \text{Yield}$$

$$D = -\ln(\text{Yield})$$

$$= -\ln(0.75)$$

$$= .287$$

Therefore, if the system which is expected to have 1.414 defects upon manufacture is stress screened so that an average of only 0.287 defects remain, the required Yield of 0.75 is achieved. If a single stress screen at the system level is employed, the stress screen must have a Test Strength of

$$1.414\,(1-TS) = 0.287$$

$$TS = 0.797$$

and if the probability of detection, P_D, is assumed to be 0.95 for the screen, the required Screening Strength is

$$SS = \frac{TS}{P_D} \quad (P_D \gg TS)$$

$$= 0.839$$

It is more likely that several stress screens at lower levels of assembly will be employed rather than one screen at the system level. Assume the following screens were selected:

Assemblies - Temperature Cycle, -50°C to 70°C, 10 cycles, 10°C/minute transition rate. $P_D = 0.90$

Units - Random Vibration, 6 g. rms, 15 minutes. $P_D = 0.85$

System - Temperature Cycle, 0°C to 40°C, 6 cycles, 5°C/minute transition rate. $P_D = 0.95$

The screening sequence is shown in Figure 3.5. The total number of estimated assembly defects are taken from the Defect Estimation Worksheets for assemblies and entered in the ASS'Y DEF block in Figure 3.5. Similarly, the number of defects in Units that are not in assemblies that are part of the units (e.g., enclosures) are entered in the UNIT DEF block. If there are system unique defects, (e.g., in interconnecting cables) they are internal in the SYSTEM DEF block. Screening strengths are determined from Tables XVII through XXI, in the draft military standard, as follows:

a. For the assembly stress screen,

Temperature Range R = 70 - (-50) = 120

Number of Cycles = 10

DT = 10

From Table XVII, the S.S. value is 0.9930

b. For the unit stress screen,

G-RMS Level = 6.0

Time = 15 minutes

From Table XX, the S.S. value is 0.772

c. For the system stress screen,

R = 40

Number of Cycles = 6

DT = 5

From Table XVII, the S.S. value is 0.5522

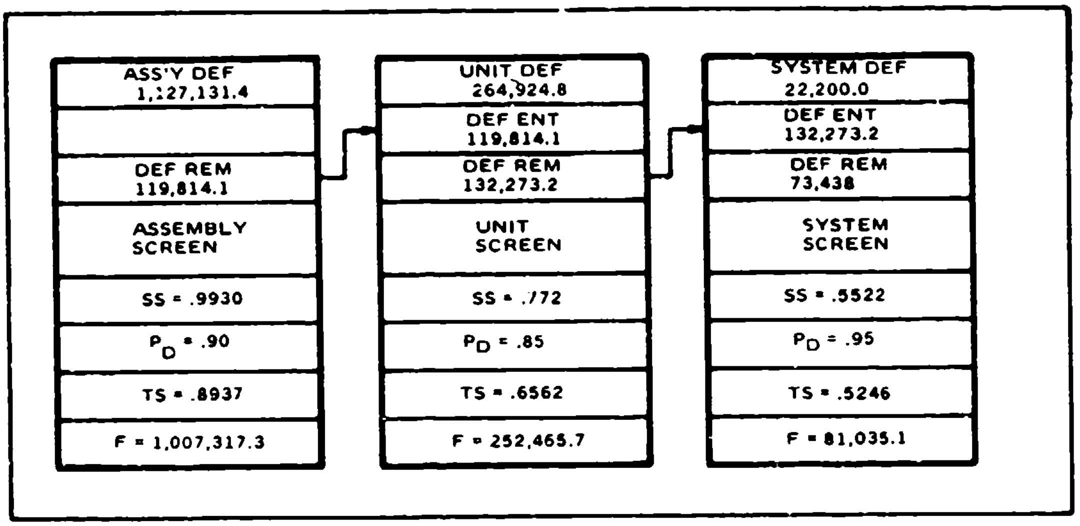

Figure 3.5. Stress Screening Sequence

Figure 3.5 shows that about 1.127 defects are present in all assemblies and that there is a fallout (F) of 1.00 defects at the assembly stress screen and 0.1198 defects escape (DEF REM) to the Unit level. Those defects plus the 0.265 unit defects are acted on by the unit stress screen, resulting in a fallout of about 0.252, with a 0.132 defects escaping to the System level. A fallout of 0.081 at the system level results in 0.073 defects remaining in the system on delivery. This number is well below the required number of 0.287, satisfying the Yield requirement. If the remaining defects exceeded the 0.287 value, three alternatives are available, viz.,

1) increase the screening strength (e.g., increase the number of temperature cycles, range, or rate of change)

2) increase test strength through more thorough testing to raise the value of P_D.

3) reduce the number of incoming defects (e.g., through use of higher quality parts, parts rescreening, improved process controls for interconnections).

When some of the assemblies are stress screened and others are not and units are subjected to different screens, the process can be handled as in the following example:

Assemblies - All manufactured assemblies are stress screened. Purchased assemblies are not screened.

Units - Some units are subjected to one type of stress screen, others to another type, and all units receive an additional third type of screen.

System - The completed system is stress screened.

The Communication System example was used and Defect Estimation Worksheets provided the estimated defects. (See Figure 3.6). As a result of the applied stress screens, the number of remaining defects is approximately 0.232, satisfying the requirement of 0.286.

3.3.2.2 Determining Test Detection Efficiency. Test Detection Efficiency (P_D) is defined as a characteristic of an operational or functional test measured by the ratio of failure modes detectable by the test to the total number of possible failure modes. P_D is a specified parameter for built-in test (BIT) and performance monitoring and fault location (PM/FL) capabilities in some procurements and if BIT or PM/FL is used primarily to verify performance of an item being stress screened, the specified P_D values should be used.

If P_D is not a specified parameter, the results of a failure modes and effects analysis (FMEA) can be used to estimate the fraction of failure modes detectable.

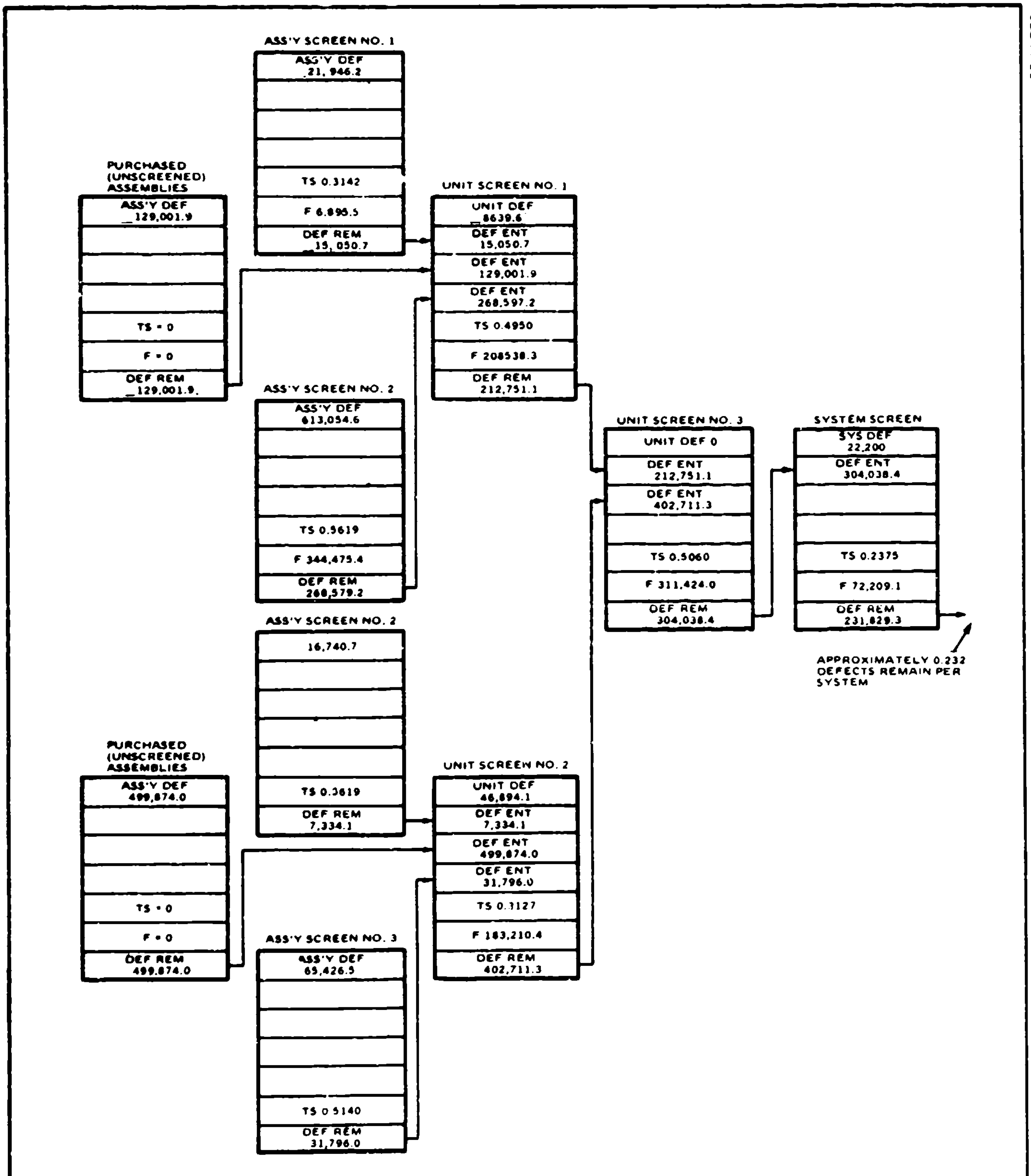

Figure 3.6. Alternate Stress Screening Sequence with Various Screens Applied at Different Levels of Assembly

If P_D is not a specified parameter and FMEA has not been made, estimates of P_D should be based on historical experience data. Such data is generally available for fixed test positions and can be estimated by test engineering personnel. Table 3.2 provides typical values for P_D for various tests applicable to stress screening. The values were derived from estimates by production and engineering test personnel.

3.3.3 Selecting and Placing Screens. The single most important task in planning a stress screening program is the selection and placement of screens. Selection must be based on an expectation of the types of defects present and knowledge, based on prior experience, of the effectiveness of stress screens against those types of defects. The screening strength values in the draft military standard apply only to the types of defects that are precipitable by the screen. Placement of screens should be based on both screening effectiveness and cost considerations. It is generally most cost effective to screen at the lowest possible level of assembly.

3.3.4 Cost-Effectiveness Tradeoff Analysis. There are innumerable alternative stress screening sequences that will precipitate the required number of defects to satisfy the Yield requirement. The task is to find the most cost effective sequence. Two examples are provided.

In the first example, a contractor is able to design a stress screening regimen that satisfies the Yield requirement with his existing facilities, requiring only a modest investment of $6,450 (line 19). The cost analysis is shown in Figure 3.7. It can be seen that the Cost per Defect Eliminated (line 26) exceeds the Threshold Cost, indicating that the proposed stress screening program is not cost effective. In the second example (Figure 3.8) a $40,000 investment cost reduces the stress screening labor by 57 percent per system screened and the Cost per Defect Eliminated is reduced below the Threshold Cost.

3.4 Development Phase Stress Screening Activity. Stress screening during the development phase is primarily intended as an experimental activity to gather information relative to the magnitude, nature, and distribution of defects and the effectiveness of applied screens. The information is to be used for design of a cost-effective stress screening program for the production phase.

Care must be taken in measuring screening fallout, particularly during the development phase. Because of the nature of product development, there will be many design-related problems that may manifest themselves as part failures that might be misconstrued as defective parts. The system may contain many nonstandard parts substituted due to lead time problems and high non-standard part fallout may not be representative of production. There is much test and maintenance activity during development resulting in induced failures, damage and degradation, which must be censored to get a measure of true defect fallout. Most importantly, it is difficult to get a measure of workmanship defects representative of production because development hardware may have been constructed in engineering laboratories

TABLE 3.2 APPROXIMATE VALUES OF DETECTION EFFICIENCY FOR VARIOUS TEST TYPES

Level Assembly	Test Type	Detection Efficiency
Assembly	Production Line GO-NO GO Test	0.85
	Production Line In-Circuit Test	0.90
	High Performance Automatic Tester	0.95
Unit	Performance Verification Test (PVT)	0.90
	Factory Checkout	0.95
	Final Acceptance Test	0.98
System	On-Line Performance Monitoring Test	0.90
	Factory Checkout Test	0.95
	Customer Final Acceptance Test	0.99

COST ANALYSIS WORKSHEET		
System/Project Communications System	Prepared By A.E. Saari	Date 3/21/85

	Cost
I. ASSEMBLY SCREENING COST	
1. Fixed Screening Cost	$1,200
2. Variable Screening Cost	2,250
3. Expected Fallout (calculate on a system basis)	0.95
4. Average Cost per Repair (if unknown, use $40)	40
5. Screening Repair Cost (multiply line 3 by line 4)	38
6. Assembly Level Screening Cost per system (add lines 2 and 5)	2,288
II. UNIT SCREENING COST	
7. Fixed Screening Cost	$3,750
8. Variable Screening Cost	3,100
9. Expected Fallout (calculate on a per-system basis)	0.34
10. Average Cost per Repair (if unknown, use $375)	375.
11. Screening Repair Cost (multiply line 9 by line 10)	90
12. Unit Level Screening Cost Per System(add lines 8 and 11)	3,190
III. SYSTEM SCREENING COST	
13. Fixed Screening Cost	1,500
14. Variable Screening Cost	2,500
15. Expected Fallout (calculate on a per system basis)	0.073
16. Average Cost per Repair (if unknown, use $750)	750.
17. Screening Repair Cost (multiply line 15 by line 16)	55
18. System Level Screening Cost per system (add lines 14 and 17)	2555
IV. TOTAL SCREENING COST	
19. Total Fixed Costs (add lines 1, 7 and 13)	6,450
20. Screening Cost/System (add lines 6, 12 and 18)	8033
21. Number of Systems to be Screened	100
22. System Screening Cost (multiply line 20 by line 21)	803,300
2[illegible]. T[illegible] Screening Cost (add lines 19 and 22)	809,750
[illegible] [illegible]out per System (add lines 3, 9 and 15)	1.263
[illegible] To[illegible] Fal[illegible] (multiply line 24 by line 21)	126.3
26 [illegible] per [illegible] [illegible]iminated (divide line 23 by 25)	6,411.
[illegible] [illegible]old [illegible] unknown, use $2000)	5,000

[illegible]RE 3.7. COST ANALYSIS WORKSHEET, EXAMPLE #1

COST ANALYSIS WORKSHEET		
System/Project Communications System	Prepared By A.E. Saari	Date 3/21/85

I. ASSEMBLY SCREENING COST	Cost
1. Fixed Screening Cost	$25,000
2. Variable Screening Cost	1,250
3. Expected Fallout (calculate on a system basis)	0.95
4. Average Cost per Repair (if unknown, use $40)	$40.
5. Screening Repair Cost (multiply line 3 by line 4)	$38.
6. Assembly Level Screening Cost per system (add lines 2 and 5)	$1,288
II. UNIT SCREENING COST	
7. Fixed Screening Cost	$10,000
8. Variable Screening Cost	$1,500
9. Expected Fallout (calculate on a per-system basis)	0.24
10. Average Cost per Repair (if unknown, use $375)	$375
11. Screening Repair Cost (multiply line 9 by line 10)	$90
12. Unit Level Screening Cost Per System(add lines 8 and 11)	$1,590
III. SYSTEM SCREENING COST	
13. Fixed Screening Cost	$5,000
14. Variable Screening Cost	$1,750
15. Expected Fallout (calculate on a per system basis)	0.073
16. Average Cost per Repair (if unknown, use $750)	$750
17. Screening Repair Cost (multiply line 15 by line 16)	$55
18. System Level Screening Cost per system (add lines 14 and 17)	$1805
IV. TOTAL SCREENING COST	
19. Total Fixed Costs (add lines 1, 7 and 13)	$40,000
20. Screening Cost/System (add lines 6, 12 and 18)	$4,683
21. Number of Systems to be Screened	100
22. System Screening Cost (multiply line 20 by line 21)	$468,300
23. Total Screening Cost (add lines 19 and 22)	$508,300
24. Expected Fallout per System (add lines 3, 9 and 15)	1.263
25. Total Fallout (multiply line 24 by line 21)	126.3
26. Cost per Defect Eliminated (divide line 23 by 25)	$4,024
27. Threshold Cost (if unknown, use $2000)	5,000

FIGURE 3.8. COST ANALYSIS WORKSHEET, EXAMPLE #2

or model shops and the observed number of workmanship defects during stress screening is not a measure of production capability. Each failure observed must be carefully analyzed to sort out the precipitated defects from all other failure sources.

3.5 <u>Production Phase Stress Screening Activity</u>. The production phase stress screening program is conducted in accordance with an approved plan. It is the intent of the draft military standard to require continuous monitoring of the stress screening results and to allow changes to the stress screening program based on cost effectiveness.

3.5.1 <u>Monitoring and Control of Stress Screens</u>. To aid in monitoring the results of stress screening, 90 percent control probability intervals were calculated as described below.

The 90 percent control probability intervals are based on the binomial distribution. This model assumes that inherent defects entering the screen fall out as a result of the screen independently of one another each with the same probability (i.e., test strength). Under these assumptions, the defect fallout from the screen has a binomial distribution:

$$P(\text{defect fallout} = k) = \binom{M}{k} TS^k (1-TS)^{M-k}, k=0,1,2,\ldots,M.$$

Here, M is the postulated number of defects entering the screen, and TS is the test strength of the screen.

The upper 90 percent probability interval limit (denoted by UL) and the lower 90 percent probability interval limit (denoted by LL) are therefore solutions to:

UL is the smallest integer such that

$$\sum_{k=UL+1}^{M} \binom{M}{k} TS^k (1-TS)^{M-k} < .05;$$

LL is the largest integer such that

$$\sum_{k=0}^{LL-1} \binom{M}{k} TS^k (1-TS)^{M-k} < .05.$$

The 90 percent control probability interval is then given by [LL, UL]. The postulated number of defects entering the screen and the postulated test strength are accepted as long as the number of defects falling out of the screen lies between LL and UL, inclusive.

TABLE 3.3. 90 PERCENT CONTROL PROBABILITY INTERVALS

Expected No. of Defects	Test Strength 0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
5	4 1	5 1	5 1	5 1	5 2	5 2	5 2	5 3	5 3	5 4
6	5 1	5 1	5 2	6 2	6 2	6 3	6 3	6 4	6 4	6 5
7	6 1	6 2	6 2	6 2	7 3	7 3	7 4	7 4	7 5	7 6
8	6 2	7 2	7 3	7 3	8 3	8 4	8 4	8 5	8 6	8 6
9	7 2	7 3	8 3	8 3	8 4	9 5	9 5	9 6	9 6	9 7
10	8 2	8 3	8 3	9 4	9 5	10 5	10 6	10 7	10 7	10 8
11	8 3	9 3	9 4	10 4	10 5	10 6	11 6	11 7	11 8	11 9
12	9 3	9 4	10 4	10 5	11 6	11 6	12 7	12 8	12 9	12 10
13	9 4	10 4	11 5	11 6	12 6	12 7	13 8	13 9	13 10	13 11
14	10 4	11 5	11 5	12 6	12 7	13 8	13 9	14 10	14 11	14 12
15	11 4	11 5	12 6	13 7	13 7	14 8	14 9	15 10	15 11	15 13
16	11 5	12 6	13 6	13 7	14 8	15 9	15 10	16 11	16 12	16 14
17	12 5	13 6	13 7	14 8	15 9	16 10	16 11	17 12	17 13	17 14
18	12 6	13 6	14 7	15 8	16 9	16 10	17 11	18 13	18 14	18 15
19	13 6	14 7	15 8	16 9	16 10	17 11	18 12	18 13	19 15	19 16
20	14 6	15 7	16 8	16 9	17 11	18 12	19 13	19 14	20 16	20 17

For example, assume that a stress screen with a test strength of 0.60 is employed and it is estimated that there are 8 defects in the item to be screened. Table 3.3 shows that if our estimates of the test strength and number of defects are correct, there is a 90 percent probability that we will observe a fallout between 3 and 7 defects.

If the observed fallout is outside the 90 percent control limits estimates of either the number of defects or test strength should be revised. Table 3.4 provides suggestions for making revised estimates.

3.5.2 <u>Failure Free Test Period Selection</u>. Each product subjected to stress screening is required to complete a failure free period, the duration of which is determined by the Yield requirement and the strength of the stress screen. Derivation of lower confidence bounds on Yield is described in paragraph 2.4 of this report. Tables 2.28 and 2.29 use the 90 percent lower confidence bounds to derive the time duration for the failure free period. For example, assume that the failure free test is to be conducted in stress screening conditions in which the defect failure rate ($\bar{\lambda}_f$) is 0.2. A 200-hour MTBF system ($N\bar{\lambda}_g$ = .005) has a Yield requirement of 0.60. Calculate $\bar{\lambda}_f/N\bar{\lambda}_g$ = 40. Using Table 2.28, enter the 40 column and proceed to the Yield requirement, 0.60. It appears on the row for which $\bar{\lambda}_f T$ = 1.7. Calculate

$$T = \frac{1.7}{\bar{\lambda}_f} = 8.5,$$

the required failure free period. If the product successfully operates without failure for a period of 8.5 hours under the stress screening conditions, there is 90 percent confidence that the Yield is at least 0.60.

TABLE 3.4. SUGGESTIONS FOR REVISING THE EXPECTED DEFECT PRECIPITATION ESTIMATES BASED ON OBSERVED RESULTS

Location of Observed Number of Defects Relative to Probability Interval			Alternative Recommended Actions					
			Assembly		Unit		System	
Assembly	Unit	System	ID	TS	ID	TS	ID	TS
Within	Within	Within	NC	NC	NC	NC	NC	NC
		Above	NC	NC	NC	NC	I	NC
		Below	NC	NC	NC	NC	D	NC
	Above	Within	NC	NC	I	NC	NC	NC
		Above	NC	NC	I	NC	NC	NC
		Below	NC	NC	I	I	NC	NC
	Below	Within	NC	NC	D	NC	NC	NC
		Above	NC	NC	NC	D	NC	NC
		Below	NC	NC	D	NC	NC	NC
Above	Within	Within	NC	I	NC	NC	NC	NC
		Above	NC	I	NC	NC	I	NC
		Below	NC	I	NC	NC	D	NC
	Above	Within	I	NC	NC	NC	NC	NC
		Above	I	NC	I	NC	NC	NC
		Below	I	NC	NC	I	NC	NC
	Below	Within	NC	I	NC	NC	NC	NC
		Above	I	NC	NC	D	NC	NC
		Below	NC	I	NC	NC	NC	NC
Below	Within	Within	D	NC	NC	NC	NC	NC
		Above	NC	D	NC	NC	NC	NC
		Below	D	NC	NC	NC	D	NC
	Above	Within	NC	D	NC	NC	NC	NC
		Above	NC	D	NC	NC	NC	NC
		Below	NC	D	NC	I	NC	NC
	Below	Within	D	NC	NC	NC	NC	NC
		Above	NC	D	NC	D	NC	NC
		Below	D	NC	D	NC	NC	NC

NC = No Change; I = Increase Est.; D = Decrease Est.
ID = Incoming Defects; TS = Strength

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2. MIL-HDBK-217D, "Reliability Prediction of Electronic Equipment", 9 April 1979, with Notice 1, 13 June 1983.

3. "Environmental Stress Screening Guidelines", Hughes Aircraft Company, June 1983.

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Appendix A

Draft Military Standard
Stress Screening of Electronic Equipment

PROPOSED MIL-STD-XXXX

MILITARY STANDARD

STRESS SCREENING OF ELECTRONIC EQUIPMENT

DEPARTMENT OF DEFENSE

WASHINGTON, DC 20301

STRESS SCREENING OF ELECTRONIC EQUIPMENT

MIL-STD-XXXX

1. This Military Standard is approved for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Rome Air Development Center, ATTN: RBE-2, Griffiss AFB NY 13441-5700, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document, or by letter.

FOREWORD

Environmental Stress Screening (ESS) programs which are applied during the production phase can yield significant improvements in field reliability as well as reductions in field maintenance costs for the Government. The benefits accrued to the manufacturer include a high degree of visibility as to the sources of problem areas in his product or process, better control of costs resulting from the so-called "hidden factory" and the opportunity to determine corrective actions which eliminate the sources of reliability problems from the hardware or production processes.

The effectiveness of ESS programs and the reliability of delivered products is measured by the number of latent defects which remain in the hardware at delivery and not solely by the number removed. The number of defects remaining in the hardware is a function of three key factors:

1. The number of design, part and manufacturing (workmanship and process) defects which reside in the hardware prior to assembly level screening.

2. The capability of the screens to precipitate flaws in the assemblies to a detectable level.

3. The thoroughness of post-screen testing which assures detection of the defects which have been precipitated to failure by the screens.

Two other equally important considerations, for effective ESS programs are:

1. The effort placed on determining defect-failure causes and their elimination through effective actions.

2. The cost-effective of ESS Programs in the sense that the cost to precipitate and remove defects from the hardware in the factory should be less than the costs to the Government if the defects were allowed to remain in the hardware and eventually fail in the field.

None of the three factors, mentioned previously, which impact the reliability of delivered products, are known with certainty. However, without some basic knowledge of their quantitative value and a reasonable assessment of their impact on the reliability of delivered hardware, effective screening programs cannot be properly planned nor evaluated. Experience data gathered from previous screening programs as well as screening experiments conducted during the development phase on new programs, can provide much of the information needed for planning effective production screening programs.

Once a screening program is implemented during production, the results must be monitored and appropriate changes made in the screening regimen to ensure that program objectives are achieved. Such changes could involve increasing screening or test detection levels so that more defects can be precipitated and detected or by reducing incoming defect levels through improved process controls.

It should be noted that it is not possible to remove all defects from the hardware. All failures are traceable to a basic part, workmanship or design defect. The vast majority of parts in the hardware have failure rates sufficiently low so that they never fail throughout the life of the product. Gross defects in the hardware tend to fail early in the field and dominate the reliability of fielded products during early life. The objective of the screening program is to remove as many of the gross defects from the hardware as is economically feasible. This standard implements these objectives through use of contractual controls on the number of defects remaining in the hardware and on the costs to precipitate and remove them.

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PROPOSED MIL-STD-XXXX

STRESS SCREENING OF ELECTRONIC EQUIPMENT

1.0 SCOPE

1.1 Purpose. This standard provides uniform procedures, methods, and guidelines for planning, monitoring, and controlling the cost effectiveness of stress screening programs for electronic equipment. It is intended to satisfy the requirements of MIL-STD-785, Reliability Program for Systems and Equipment Development and Production, Task 301, Environmental Stress Screening.

1.2 Application. This standard is applicable to the development and production of electronic equipment for the Department of Defense. It covers contractor activities required during the development and preproduction stages to prepare a stress screening program for approval by the procuring activity (PA). It also contains contractor tasks required for monitoring and controlling the screening process during production.

1.3 Tailoring of Tasks. Tasks described in the Detailed Requirements Section are intended to be tailored as appropriate to satisfy the individual needs of the equipment being procured.

2.0 REFERENCE DOCUMENTS

2.1 Government Documents. The following documents of the issue in effect on the date of invitation for bids or request for proposal form a part of this standard to the extent specified herein.

MILITARY STANDARDS

MIL-STD-280	Definitions of Item Levels, Item Interchangeability, Models, and Related Terms.
MIL-STD-721	Definition of Effectiveness Terms for Reliability, Maintainability, Human Factors and Safety.
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production.

PUBLICATIONS

MIL-HDBK-217	Reliability Prediction of Electronic Equipment.
NAVMAT P9492	Navy Manufacturing Screening Program.

2.2 Other Publications. The following documents form a part of this standard to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bids or request for proposal shall apply.

Library of Congress 62-38584 ISBN 0-915414-66-X	Environmental Stress Screening Guidelines, published by the Institute of Environmental Sciences.
RADC-TR-82-87	Stress Screening of Electronic Hardware.
RADC-TR-86-149	Environmental Stress Screening.

(Copies of specifications, standards, drawings and publications required by manufacturers in connection with specific acquisition functions should be obtained from the Procuring Activity or as directed by the Contracting Officer.)

3.0 DEFINITIONS AND ACRONYMS

3.1 Definitions. Definitions applicable to this standard are listed below:

a.	Detectable Failure	A failure that can be detected with 100% test detection efficiency.
b.	Detection Efficiency	(See Test Detection Efficiency)
c.	Failure-Free Period	A contiguous period of time during which an item is to operate without the occurrence of a failure.
d.	Failure-Free Test	A test to determine if an equipment item can operate without failure for a predetermined time period under specific stress conditions.
e.	Fallout	Failures observed during, or immediately after, and attributed to stress screens.
f.	Fraction Defective	The number of defects contained in a population divided by the total population.
g.	Latent Defect	An inherent weakness that has a high probability of resulting in an early life failure.
h.	Patent Defect	A failure, usually one waiting to be detected without the need for stress screens.
i.	Precipitation (of defects)	The process of transforming a latent defect into a patent defect.
j.	Screening Effectiveness	Generally, a measure of the ability of a screen to precipitate defects. Sometimes used specifically to mean screening strength.
k.	Screening Parameters	Constants in screening strength equations with variable values that refer to screening strength, e.g., vibration g-levels, temperature rate of change and time duration.

l.	Screening Sequence	A combination of stress screens applied to an equipment, identified in the order of application (i.e., assembly, unit, and system screens).
m.	Screening Strength	The probability that a screen will precipitate a defect, given that a defect is present.
n.	Selection and Placement	The process of systematically selecting the most effective stress screens and placing them at the appropriate levels of assembly.
o.	Stress Screening	The process of applying mechanical, electrical and/or thermal stresses to an equipment item for the purpose of precipitating latent part and workmanship defects.
p.	Test Detection Efficiency	A characteristic of a test measured by the ratio of the number of failure modes detectable to the total number of failure modes.
q.	Test Strength	The product of screening strength and test detection efficiency. A measure of the probability that a defect will be precipitated and detected in a screen.
r.	Thermal Survey	The measurement of thermal response characteristics at points of interest within an equipment when temperature extremes are applied to the equipment.
s.	Vibration Survey	The measurement of vibration response characteristics at points of interest within an equipment when vibration excitation is applied to the equipment.
t.	Yield	The probability that an equipment is free of defects when offered for acceptance.

3.2 Acronyms. Acronyms used in this document are defined as follows:

CDRL	Contract Data Requirements List
CND	Cannot Duplicate

ESS	Environmental Stress Screening
FFT	Failure-Free Tests
NFF	No Fault Found
PA	Procuring Activity
RTOK	Retest OK
SS	Screening Strength
TS	Test Strength

4.0 GENERAL REQUIREMENTS

4.1 Application of Stress Screening. The use of stress screening, as a process for eliminating part and workmanship defects during manufacture, shall be considered for all deliverable equipment. Consideration shall be given during the concept formulation phase to assure that time and resources are available during development for the proper application stress screening. The intended use of stress screening during development shall be described in contractors' proposals.

4.2 Objectives of Stress Screening. The primary objective of stress screening during the production phase shall be to transform latent part and workmanship defects in equipment into detectable failures for their elimination prior to delivery to the ultimate users of the equipment. During the development phase the primary objective shall be to determine the most effective stress screens to be employed during the production phase. Therefore, experimentation with various screens and screening parameters during development shall be conducted to the maximum extent practical.

4.3 Integration of Stress Screening with other Reliability Program Activivities. Stress screening shall be integrated to the maximum extent practical with find-and-fix, reliability development and qualification testing and failure reporting, analysis and corrective action programs.

4.4 Equipment and Process Characterization. Contractors shall perform analyses as required to develop a data base of latent part and workmanship defect magnitudes and distribution unique to his equipment and manufacturing processes. The data base shall also include test detection efficiencies for the various tests employed as a part of stress screening. The contractor's data base shall be used in lieu of generic data provided in this standard.

4.5 Pre- and Post-Screen Testing. Testing before and after stress screens shall be required to ensure that patent defects are removed prior to screening and shall continue until screening effectiveness is established. The tests performed before screening shall be essentially the same as those performed after screening.

4.6 Data Recording. Data related to stress screening (names, dates, places, facilities and equipment used, screening parameters, part serial numbers of equipment screened, fallout, cost data, etc.) shall be recorded and maintained in sufficient detail for evaluation of screening effectiveness.

4.7 Reporting. Reporting of stress screening progress and status shall be as required by the Contract Data Requirements List (CDRL) (DD Form 1423) provided as part of the contract.

4.8 Requirements Specified by the PA. The PA will specify YIELD and COST THRESHOLD in accordance with guidelines provided in Appendix A.

5.0 DETAIL REQUIREMENTS

5.1 Development Phase ESS Planning Requirements.

5.1.1 Estimation of the Number of Defects.

5.1.1.1 General. The number of defects in the equipment to be screened shall be estimated by the methods defined herein. Alternate methods may be used with prior approval of the PA.

This standard uses a three-level equipment breakdown structure, viz., System, Unit and Assembly to illustrate the methodology for conduct of a stress screening program. Numerous other equipment breakdown structures are possible and can be adapted to the structure used herein. Using the equipment definitions of MIL-STD-280, the System level can also be used as the Subsystem or Set level; the Unit level can also be used as Group level; and the Assembly level can be used as the Subassembly level. Stress screening, excluding part level screening, is generally confined to a maximum of three levels. However, if more levels are used, the methodology of this standard is equally applicable, requiring only the expansion of the three-level worksheets.

5.1.1.2 System Breakdown. The system to be screened shall be defined to the assembly level in breakdown charts as shown in Figures 1 and 2. Figure 1 shows a breakdown of a system to be screened into the three units comprising the system. Figure 2 shows a breakdown of one of the units into its constituent assemblies.

5.1.1.3 Assembly Defect Estimates. For each assembly identified in the Unit Breakdown Chart, a worksheet as shown in Figure 3 shall be completed as follows:

a. Part Type. Part types shown on the worksheet are the standard types included in MIL-HDBK-217. Miscellaneous part types shall be added as appropriate.

b. Quality Level. Enter the appropriate quality level as identified in Table I.

c. Quantity. Enter the quantity of each part type.

d. Fraction Defective. Determine the fraction defective for each part type from Tables II through XIII and enter on the worksheet.

e. Estimated Defects. Determine the estimated number of defects by multiplying the quantity by the fraction defective and enter on the worksheet.

f. Totals. Enter the total estimated number of defects on the worksheet and enter on the corresponding space of the Unit Breakdown Chart.

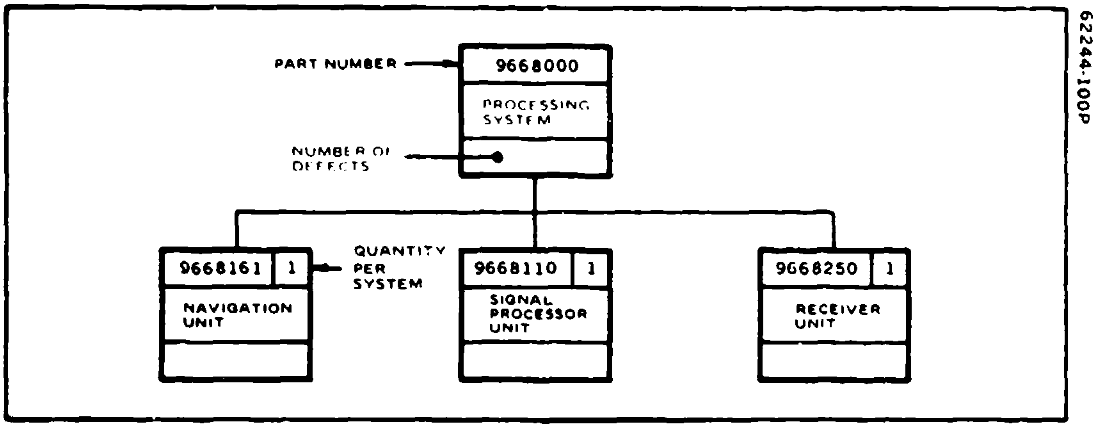

Figure 1. System Breakdown Chart

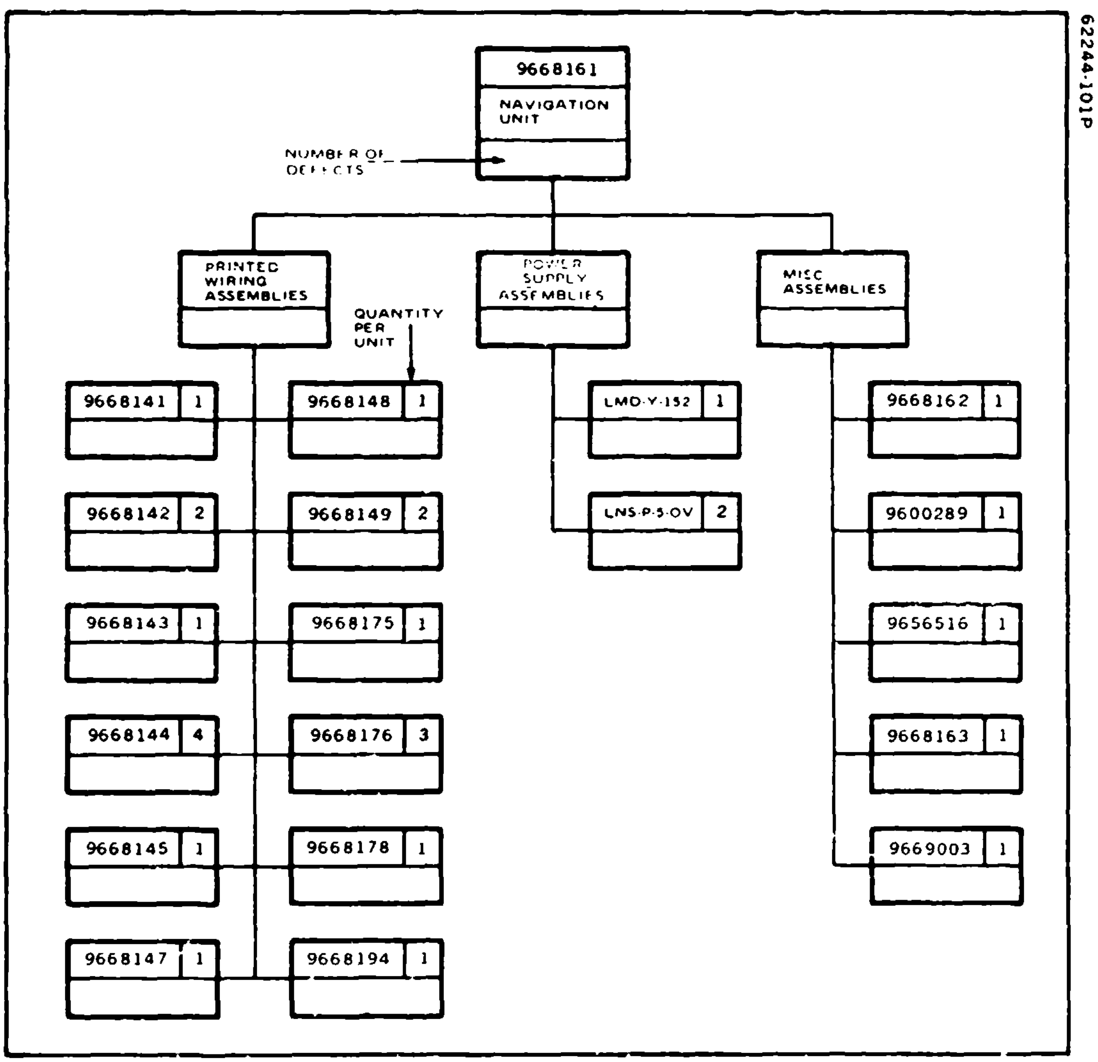

Figure 2. Unit Breakdown Chart

DEFECT ESTIMATION WORKSHEET

Program/Project	System Nomenclature

Unit	Assembly	Prepared By	Date

Part Type	Quality Level	Quantity	Fraction Defective	Estimated Defects
Microelectronic Devices				
Transistors				
Diodes				
Resistors				
Capacitors				
Inductive Devices				
Rotating Devices				
Relays				
Switches				
Connectors				
Printed Wiring Boards				
Connections, Hand Solder				
Connections, Crimp				
Connections, Weld				
Connections, Solderless Wrap				
Connections, Wrapped and Soldered				
Connections, Clip Termination				
Connections, Reflow Solder				
			Total No. of Defects	

Figure 3. Worksheet for Estimating Number of Defects

5.1.1.4 Unit Defect Estimates. For each unit identified in the system breakdown Chart, a Unit Breakdown Chart, as shown in Figure 2, shall be prepared. A Defect Estimation Worksheet shall be completed as was done with assemblies, including only those parts in the unit that are not already included in assemblies comprising the unit and estimated unit flaws. Enter totals on the Equipment Breakdown Chart in the spaces provided.

5.1.1.5 System Defect Estimate. A Defect Estimation Worksheet shall be completed for the System to be screened to estimate the number of defects not included in Unit estimates. Determine the total estimated number of defects in the System by summing the Unit defect estimates and the quantity from the System defect estimate. This total is the number of defects that are introduced into the System during its manufacture.

5.1.2 Determination of Required Test Strength.

5.1.2.1 General. The required screening strength is dependent on three variables,

(1) Required Yield,
(2) Estimated Defects, and
(3) Test Detection Efficiency

Yield is specified by the PA per guidance in Appendix A. Yield is translated into a mean number of defects per item by

$$D = -\ln(\text{Yield}) \qquad (2)$$

This value shall be used as the goal for the number of defects remaining upon completion of manufacture (including screening) of items offered to the PA for acceptance. Screening strength required is that which will reduce the estimated number of defects remaining, taking into consideration that all defects transformed to detectable failures will not be detected (detection efficiency).

TABLE I. QUALITY LEVELS FOR VARIOUS PART TYPES

Part Type	Quality Levels
Microelectronic Devices	S, B, B-0, B-1, B-2, C, C-1, D, D-1
Transistors	JANTXV, JANTX, JAN, LOWER, PLASTIC
Diodes	JANS, JANTXV, JANTX, JAN, LOWER, PLASTIC
Resistors	S, R, P, M, MIL-SPEC, LOWER
Capacitors	S, R, P, M, L, MIL-SPEC, LOWER
Transformers	MIL-SPEC, LOWER
Coils	S, R, P, M, MIL-SPEC, LOWER
Relays	MIL-SPEC, LOWER
Switches	MIL-SPEC, LOWER
Connectors	MIL-SPEC, LOWER
Printed Wiring Boards	MIL-SPEC, LOWER

TABLE II. FRACTION DEFECTIVE, MICROELECTRONIC DEVICES ($DEFECTS/10^6$)

	Quality Level								
Environment	S	B	B-0	B-1	B-2	C	C-1	D	D-1
GB	9.2	18.3	36.6	54.9	119.0	146.4	237.9	320.3	640.6
GF	19.4	38.7	77.4	116.1	251.6	309.6	503.2	677.3	1354.6
GM	27.5	55.1	110.1	165.2	357.9	440.5	715.8	963.6	1927.2
MP	25.6	51.2	102.4	153.6	332.9	409.7	665.8	896.3	1792.5
NSB	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
NS	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
NU	34.7	69.5	139.0	208.5	451.7	556.0	903.5	1216.2	2432.5
NH	35.7	71.4	142.8	214.3	464.3	571.4	928.5	1249.9	2499.9
NUU	37.6	75.3	150.5	225.8	489.3	602.2	978.6	1317.3	2634.6
ARW	48.2	96.4	192.9	289.3	626.9	771.6	1253.8	1687.8	3375.6
AIC	19.4	38.7	77.4	116.1	251.6	309.6	503.2	677.3	1354.6
AIT	21.8	43.5	87.0	130.5	282.9	348.9	565.7	761.5	1523.1
AIB	31.4	62.8	125.5	188.3	408.0	502.1	815.9	1098.4	2196.7
AIA	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
AIF	36.2	72.4	144.8	217.2	470.5	579.1	941.0	1266.8	2533.5
AUC	21.8	43.5	87.0	130.5	282.9	348.1	565.7	761.5	1523.1
AUT	26.6	53.1	106.3	159.4	345.4	425.1	690.8	929.9	1859.9
AUB	43.4	86.8	173.6	260.5	564.3	694.6	1128.7	1519.4	3038.8
AUA	36.2	72.4	144.8	217.2	470.5	579.1	941.0	1266.8	2533.5
AUF	50.6	101.3	202.5	303.8	658.2	810.1	1316.4	1772.0	3544.0
SF	11.7	23.3	46.6	69.9	151.5	186.4	303.0	407.9	815.7
MFF	26.1	52.2	104.4	156.5	339.2	417.4	678.3	913.1	1826.2
MFA	33.3	66.6	133.2	199.8	433.0	532.9	866.0	1165.7	2331.4
USL	60.3	120.5	241.0	361.5	783.3	964.0	1566.6	2108.8	4217.7
ML	69.9	139.8	279.5	419.3	908.4	1118.0	1816.8	2445.7	4891.3
CL	1065.9	2131.8	4263.7	6395.5	13857.0	17054.8	27714.0	37307.4	74614.7

TABLE III. FRACTION DEFECTIVE, TRANSISTORS (DEFECTS/10^6)

	Quality Level				
Environment	JANTXV	JANTX	JAN	Lower	Plastic
GB	10.9	21.9	109.3	546.6	1093.2
GF	34.6	69.2	346.0	1730.2	3460.4
GM	98.8	189.5	947.7	4738.5	9477.0
MP	65.2	130.4	651.8	3259.0	6518.0
NSB	54.3	108.7	543.3	2716.5	5433.1
NS	54.3	108.7	543.3	2716.5	5433.1
NU	109.6	219.1	1095.7	5478.3	10956.6
NH	99.7	199.4	997.0	4985.1	9970.2
NUU	104.6	209.3	1046.3	5231.7	10463.4
ARW	139.2	278.3	1391.6	6957.8	13915.6
AIC	52.9	105.7	528.5	2642.6	5285.1
AIT	80.0	160.0	799.8	3998.8	7997.5
AIB	178.6	357.2	1786.1	8930.5	17860.9
AIA	104.6	209.3	1046.3	5231.7	10463.4
AIF	203.3	406.5	2032.7	10163.4	20326.8
AUC	80.0	160.0	799.8	3998.8	7997.5
AUT	129.3	258.6	1292.9	6464.6	12929.2
AUB	301.9	603.8	3019.0	15095.1	30190.1
AUA	178.6	357.2	1786.1	8930.5	17860.9
AUF	326.6	653.1	3265.6	16328.0	32656.0
SF	8.0	15.9	79.7	398.6	797.3
MFF	65.2	130.4	651.8	3259.0	6518.0
MFA	89.8	179.7	898.4	4491.9	8983.9
USL	183.5	367.1	1835.4	9177.0	18354.1
ML	208.2	416.4	2082.0	10410.0	20819.9
CL	3408.9	6817.7	34088.7	170443.3	340886.7

TABLE IV. FRACTION DEFECTIVE, DIODES (DEFECTS/10^6)

	Quality Level					
Environment	JANS	JANTXV	JANTX	JAN	Lower	Plastic
GB	1.2	5.9	11.8	59.2	296.2	592.3
GF	1.7	8.6	17.2	86.0	430.0	860.0
GM	4.3	21.16	43.2	216.2	1080.8	2161.5
MP	3.2	16.1	32.2	160.8	803.8	1607.7
NSB	1.9	9.4	18.9	94.3	471.5	943.1
NS	1.9	9.4	18.9	94.3	471.5	943.1
NU	4.9	24.4	48.8	243.8	1219.2	2438.5
NUU	4.7	23.5	46.9	234.6	1173.1	2346.2
ARW	6.0	29.9	59.8	299.2	1496.2	2992.3
AIC	3.8	18.8	37.7	188.5	942.3	1884.6
AIT	4.7	23.5	46.9	234.6	1173.1	2346.2
AIB	6.5	32.7	65.4	326.9	1634.6	3269.2
AIA	5.6	28.1	56.2	280.8	1403.8	2807.7
AIF	7.5	37.3	74.6	373.1	1865.4	3730.8
AUC	5.6	28.1	56.2	280.8	1403.8	2807.7
AUT	6.5	32.7	65.4	326.9	1634.6	3269.2
AUB	10.2	51.2	102.3	511.5	2557.7	5115.4
AUA	8.4	41.9	83.8	419.2	2096.2	4192.3
AUF	10.2	51.2	102.3	511.5	2557.7	5115.4
SF	1.2	5.9	11.8	59.2	296.2	592.3
MFF	3.2	16.1	32.2	160.8	803.9	1607.7
MFA	4.1	20.7	41.4	206.9	1034.6	2069.2
USL	7.6	38.2	76.5	382.3	1911.5	3823.1
ML	8.6	42.8	85.7	428.5	2142.3	4284.6
CL	128.4	641.9	1283.8	6419.2	32096.2	64192.3

TABLE V. FRACTION DEFECTIVE, RESISTORS (DEFECTS/10^6)

	Quality Level					
Environment	S	R	P	M	MIL-SPEC	Lower
GB	0.4	1.2	3.7	12.3	61.4	184.2
GF	0.6	2.0	6.1	20.3	101.7	305.2
GM	1.5	5.1	15.4	51.5	257.4	772.3
MP	1.7	5.7	17.2	57.2	286.2	858.7
NSB	0.9	3.1	9.2	30.7	153.6	460.9
NS	1.0	3.4	10.1	33.6	168.1	504.2
NU	2.6	8.7	26.2	87.2	436.2	1308.5
NH	2.6	8.7	26.2	87.2	436.2	1308.5
NUU	2.8	9.3	27.9	93.0	465.0	1395.0
ARW	3.5	11.6	34.8	116.1	580.3	1740.9
AIC	0.6	2.1	6.3	20.9	104.6	313.9
AIT	0.7	2.4	7.1	23.8	119.0	357.1
AIB	1.3	4.4	13.2	44.0	219.9	659.8
AIA	1.2	4.1	12.3	41.1	205.5	616.6
AIF	1.8	5.8	17.5	58.4	292.0	876.0
AUC	1.4	4.7	14.1	46.9	234.4	703.1
AUT	1.3	4.4	13.2	44.0	219.9	659.8
AUB	2.8	9.3	27.9	93.0	465.0	1395.0
AUA	2.8	9.3	27.9	93.0	465.0	1395.0
AUF	3.7	12.2	36.5	121.8	609.1	1827.4
SF	0.3	0.9	2.6	8.8	44.1	132.3
MFF	1.7	5.8	17.3	57.8	289.1	867.4
MFA	2.3	7.6	22.7	75.7	378.5	1135.5
USL	4.7	15.6	46.9	156.4	782.1	2346.3
ML	5.4	17.9	53.8	179.5	897.4	2692.2
CL	88.4	294.7	884.1	2947.0	14735.0	44205.0

TABLE VI. FRACTION DEFECTIVE, CAPACITORS (DEFECTS/10^6)

	Quality Level						
Environment	S	R	P	M	L	MIL-SPEC, Non-ER	Lower
GB	1.2	3.8	11.5	38.4	115.3	115.3	384.4
GF	1.8	6.2	18.4	61.5	184.5	184.5	615.0
GM	9.0	30.0	89.9	299.8	899.4	899.4	2998.1
MP	12.7	42.3	126.8	422.8	1268.4	1268.4	4228.1
NSB	5.8	19.2	57.7	192.2	576.6	576.6	1921.9
NS	6.3	21.1	63.4	211.4	634.2	634.2	2114.1
NU	14.3	47.7	143.0	476.6	1429.9	1429.9	4766.2
NH	18.4	61.5	184.5	615.0	1845.0	1845.0	6150.0
NUU	20.8	69.2	207.6	691.9	2075.6	2075.6	6918.7
ARW	27.7	92.2	276.7	922.5	2757.5	2767.5	9225.0
AIC	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIT	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIB	5.8	19.2	57.7	192.2	576.6	576.6	1921.9
AIA	3.5	11.5	34.6	115.3	345.9	345.9	1153.1
AIF	6.9	23.1	69.2	230.6	691.9	691.9	2306.2
AUC	8.6	28.8	86.5	288.3	864.8	864.8	2882.8
AUT	9.2	30.7	92.2	307.5	922.5	922.5	3075.0
AUB	11.5	38.4	115.3	384.4	1153.1	1153.1	3843.7
AUA	9.2	30.7	92.2	307.5	922.5	922.5	3075.0
AUF	17.3	57.7	173.0	576.6	1729.7	1729.7	5765.6
SF	0.9	3.1	9.2	30.7	92.2	92.2	307.5
MFF	12.7	42.3	126.8	422.8	1268.4	1268.4	4228.1
MFA	17.3	57.7	173.0	576.6	1729.7	1729.7	5765.6
USL	36.9	123.0	369.0	1230.0	3690.0	3690.0	12300.0
ML	41.5	138.4	415.1	1383.7	4151.2	4151.2	13837.5
CL	703.4	2344.7	7034.1	23446.9	70340.6	70340.6	234468.6

TABLE VII. FRACTION DEFECTIVE, INDUCTIVE DEVICES (DEFECTS/10^6)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	537.2	1790.7
GF	1222.9	4076.4
GM	2142.0	7140.1
MP	1996.1	6653.8
NSB	1135.4	3784.6
NS	1222.9	4076.4
NU	2433.8	8112.7
NH	2725.6	9085.3
NUU	3017.4	10058.0
ARW	3892.7	12975.8
AIC	1047.8	3492.8
AIT	1266.7	4222.3
AIB	1266.7	4222.3
AIA	1266.7	4222.3
AIF	1704.4	5681.2
AUC	1339.6	4465.4
AUT	1339.6	4465.4
AUB	1485.5	4951.7
AUA	485.5	4951.7
AUF	1850.3	6167.5
SF	537.2	1790.7
MFF	1996.1	6653.8
MFA	2579.7	8599.0
USL	5059.9	16866.2
ML	5643.4	18811.5
CL	89385.3	297951.1

TABLE VIII. FRACTION DEFECTIVE, ROTATING DEVICES

Environment	Fraction Defective (Defects/10^6)
GB	5935.2
GF	11663.1
GM	30168.5
MP	27965.5
NSB	14967.6
NS	16289.4
NU	34574.6
NH	38980.6
NUU	43386.7
ARW	56604.8
AIC	12544.3
AIT	13645.8
AIB	15848.8
AIA	13645.8
AIF	23559.4
AUC	14747.3
AUT	18051.9
AUB	20254.9
AUA	18051.9
AUF	25762.5
SF	5935.2
MFF	27965.5
USL	74229.1
ML	83041.2
CL	*******

TABLE IX. FRACTION DEFECTIVE, RELAYS (DEFECTS/10^6)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	142.5	210.9
GF	231.4	388.8
GM	635.1	1784.5
MP	1510.8	4384.3
NSB	621.4	1716.0
NS	621.4	1716.0
NU	1031.9	2673.9
NH	2263.4	6642.0
NUU	2400.2	6915.7
ARW	3221.2	9652.3
AIC	450.3	724.0
AIT	484.5	1100.3
AIB	758.2	1442.4
AIA	587.2	1100.3
AIF	758.2	1784.5
AUC	621.4	1442.4
AUT	689.8	1784.5
AUB	1100.3	2810.7
AUA	758.2	2126.5
AUF	1100.3	3152.8
SF	142.5	210.9
MFF	1510.8	4384.3
MFA	2058.1	5684.2
USL	4315.8	13073.1
ML	4931.6	14441.4
CL	N/A	N/A

TABLE X. FRACTION DEFECTIVE, SWITCHES (DEFECTS/10^6)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	1.4	24.4
GF	2.4	44.0
GM	8.8	158.4
MP	12.8	230.6
NSB	5.3	95.5
NS	5.3	95.5
NU	12.2	220.3
NUU	20.3	364.7
ARW	27.1	488.4
AIC	5.4	96.6
AIT	5.4	96.6
AIB	9.4	168.8
AIA	9.4	168.8
AIF	12.2	220.3
AUC	6.5	117.2
AUT	6.5	117.2
AUB	12.2	220.3
AUA	12.2	220.3
AUF	15.1	271.9
SF	1.4	24.4
MFF	12.8	230.6
MFA	17.4	313.1
USL	36.9	663.7
ML	41.5	746.2
CL	688.3	12388.6

TABLE XI. FRACTION DEFECTIVE, CONNECTORS (DEFECTS/10^6)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	73.7	97.3
GF	83.2	248.1
GM	417.7	1204.6
MP	427.1	827.7
NSB	219.8	408.3
NS	276.3	544.9
NU	639.2	1298.9
NH	639.2	1251.8
NUU	686.3	1346.0
ARW	921.9	1770.1
AIC	120.9	497.8
AIT	168.0	497.8
AIB	238.7	733.4
AIA	215.1	733.4
AIF	332.9	969.0
AUC	262.2	733.4
AUT	403.6	733.4
AUB	497.8	969.0
AUA	474.3	969.0
AUF	733.4	1440.2
SF	73.7	97.3
MFF	427.1	827.7
MFA	592.1	1157.5
USL	1204.6	2382.7
ML	1393.1	2759.6
CL	21335.8	45733.8

TABLE XII. FRACTION DEFECTIVE, PRINTED WIRING BOARDS (DEFECTS/106)

	Quality Level	
Environment	MIL-SPEC	Lower
GB	425.0	4250.0
GF	690.3	6903.2
GM	1792.4	17925.3
MP	1629.2	16291.5
NSB	1057.7	10576.9
NS	1302.6	13026.0
NU	2670.0	26700.3
NH	2874.1	28741.2
NUU	3078.2	30782.2
ARW	4098.7	40986.9
AIC	731.1	7311.4
AIT	1139.3	11393.2
AIB	1853.7	18536.5
AIA	1567.9	15679.2
AIF	2261.8	22618.4
AUC	1751.6	17516.1
AUT	3282.3	32823.1
AUB	5323.3	53232.5
AUA	4302.8	43027.8
AUF	7364.2	73641.9
SF	425.0	4250.0
MFF	1996.5	19965.2
MFA	2670.0	26700.3
USL	5527.3	55273.5
ML	6139.6	61396.3
CL	102267.9	*******

TABLE XIII. FRACTION DEFECTIVE, CONNECTIONS (DEFECTS/10^6)

Environment	Connection Type						Crimp			
	Hand Solder	Weld	Solderless Wrap	Wrapped and Soldered	Clip Term	Reflow Solder	Auto	Man., Upper	Man., Std.	Man., Lower
GM	12.	0.2	0.02	1.	1.	0.3	1.2	1.2	2.5	24.8
GF	26.	0.5	0.03	1.	1.	0.7	2.6	2.6	5.2	52.0
GM	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
MP	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
NSB	43.	0.8	0.06	2.	2.	1.1	4.3	4.3	8.7	86.7
NS	54.	1.0	0.07	3.	3.	1.4	5.4	5.4	10.9	109.0
NU	123.	2.4	0.16	7.	6.	3.3	12.3	12.3	24.5	245.1
NH	136.	2.6	0.18	7.	6.	3.6	13.6	13.6	27.2	272.4
NUU	149.	2.9	0.20	8.	7.	3.9	14.9	14.9	29.7	297.1
ARW	198.	3.8	0.27	11.	9.	5.3	19.8	39.6	39.6	396.2
AIC	31.	0.6	0.04	2.	1.	0.8	3.1	3.1	6.2	61.9
AIT	56.	1.1	0.07	3.	3.	1.5	5.6	5.6	11.1	111.4
AIB	68.	1.3	0.09	4.	3.	1.8	6.8	6.8	13.6	136.2
AIA	62.	1.2	0.08	3.	3.	1.6	6.2	6.8	12.4	123.8
AIF	93.	1.8	0.12	5.	4.	2.5	9.3	9.3	18.6	185.7
AUC	37.	0.7	0.05	2.	2.	1.0	3.7	3.7	7.4	74.3
AUT	74.	1.4	0.10	4.	3.	2.0	7.4	7.4	14.9	148.6
AUB	93.	1.8	0.12	5.	4.	2.5	9.3	9.3	18.6	185.7
AUA	87.	1.7	0.12	5.	4.	2.5	9.3	9.3	18.6	185.7
AUF	118.	2.3	0.16	6.	5.	3.1	11.8	11.8	23.5	235.2
SF	12.	0.2	0.02	1.	1.	0.3	1.2	2.5	2.54	24.8
MFF	90.	1.7	0.12	5.	4.	2.4	9.0	9.0	18.1	180.8
MFA	124.	2.4	0.17	7.	6.	3.3	12.4	12.4	24.8	247.6
USL	272.	5.2	0.37	15.	13.	7.2	27.2	27.2	54.5	544.8
ML	310.	6.0	0.42	17.	14.	8.2	31.0	31.0	61.9	619.0
CL	5200.	100.0	7.00	280.	240.	138.0	520.0	520.0	1040.0	10400.0

5.1.2.2 Detection Efficiency (P_D). Detection efficiency is an important factor in the elimination of defects. While stress screens may be effective in transforming a defect into a detectable failure, removal of the failure is dependent on the ability of the test used to detect the failure. With the increased complexity of modern electronics, fault sites may be confined to smaller areas and fault symptoms may appear only during certain tests or under a special set of external conditions, resulting in an increasing incidence of "cannot duplicate" (CND), "No-fault found" (NFF), "retest OK" (RTOK), and similar intermittent or transient phenomena. Values for test detection efficiency (P_D) shall be determined for each test applied during stress screening. Table XIV may be used as default values until actual P_D values are determined.

Application of power to equipment during a screen, exercising the equipment, and monitoring equipment performance continuously during the screen greatly enhances detection efficiency. Subtle faults such as contact intermittents or temperature sensitive parts can only be detected with powered and monitored screens.

5.1.2.3 Test Strength for a Single Screen Following Manufacture. The relationship of estimated number of defects (D_{in}), number of defects remaining (D) and test strength (TS) is,

$$D = D_{in}(1-TS)$$

where TS is the product of screening strength (SS) and detection efficiency (P_D). Required test strength is determined by

$$TS = 1 - \frac{D}{D_{in}}$$

and required screening strength by

$$SS = TS/P_D \qquad (TS \leqslant P_D)$$

5.1.2.4 Test Strength for Multiple Screens During Manufacture. Selection of required screens or screening sequences to achieve the required test strength shall be accomplished by an iterative process of

(1) initial screen selection and placement
(2) remaining defects calculation
(3) screen modification
(4) recalculation of remaining defects

until the selected screens result in the desired number of defects precipitated and detected. A diagram as shown in Figure 4 shall be used in calculating the remaining flaws in a multi-level screening sequence, particularly when screening is applied selectively. This task must be accomplished simultaneously with screen selection and placement described in paragraph 5.1.3.

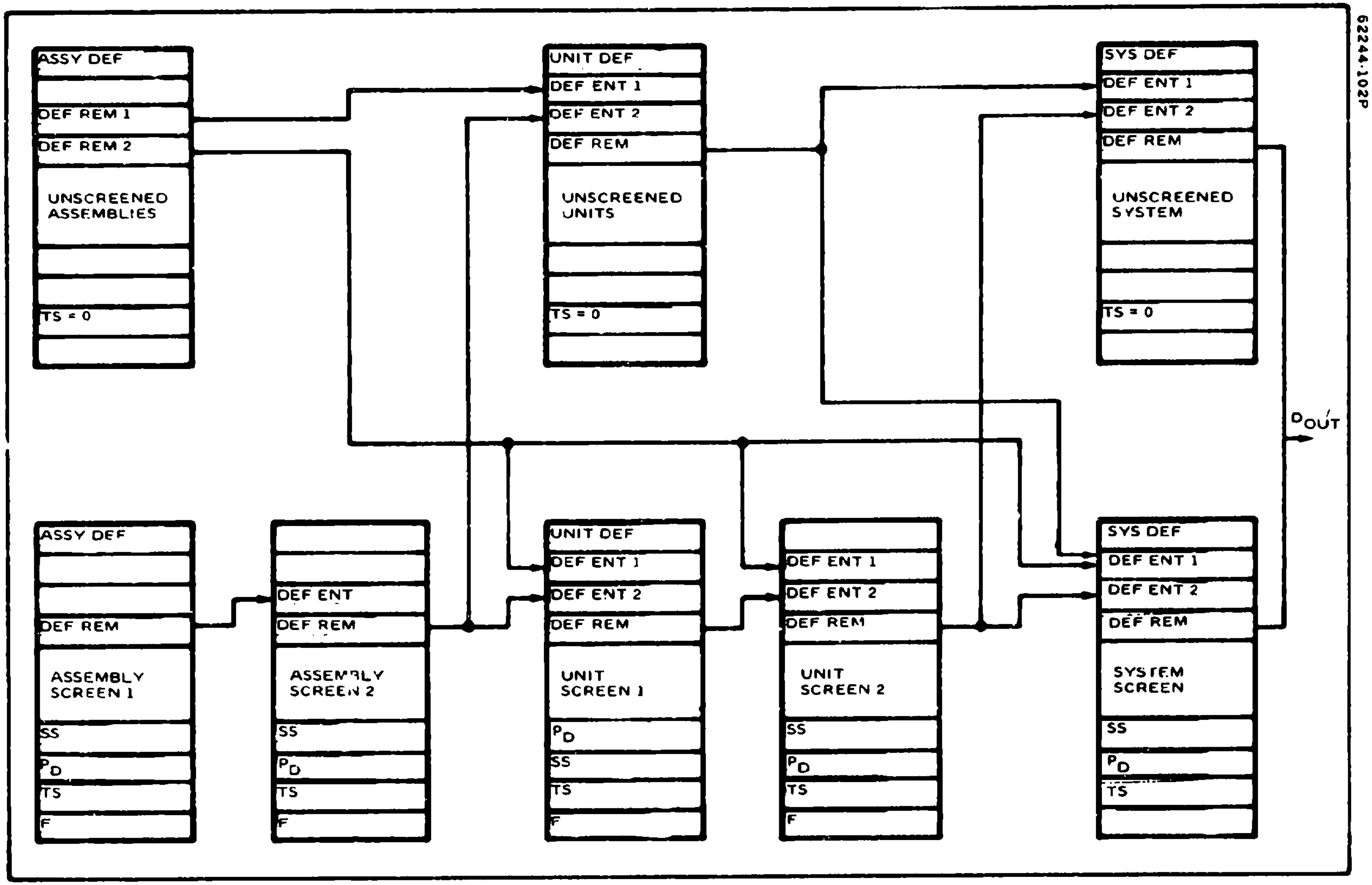

Figure 4. Multilevel Screening Flow Chart

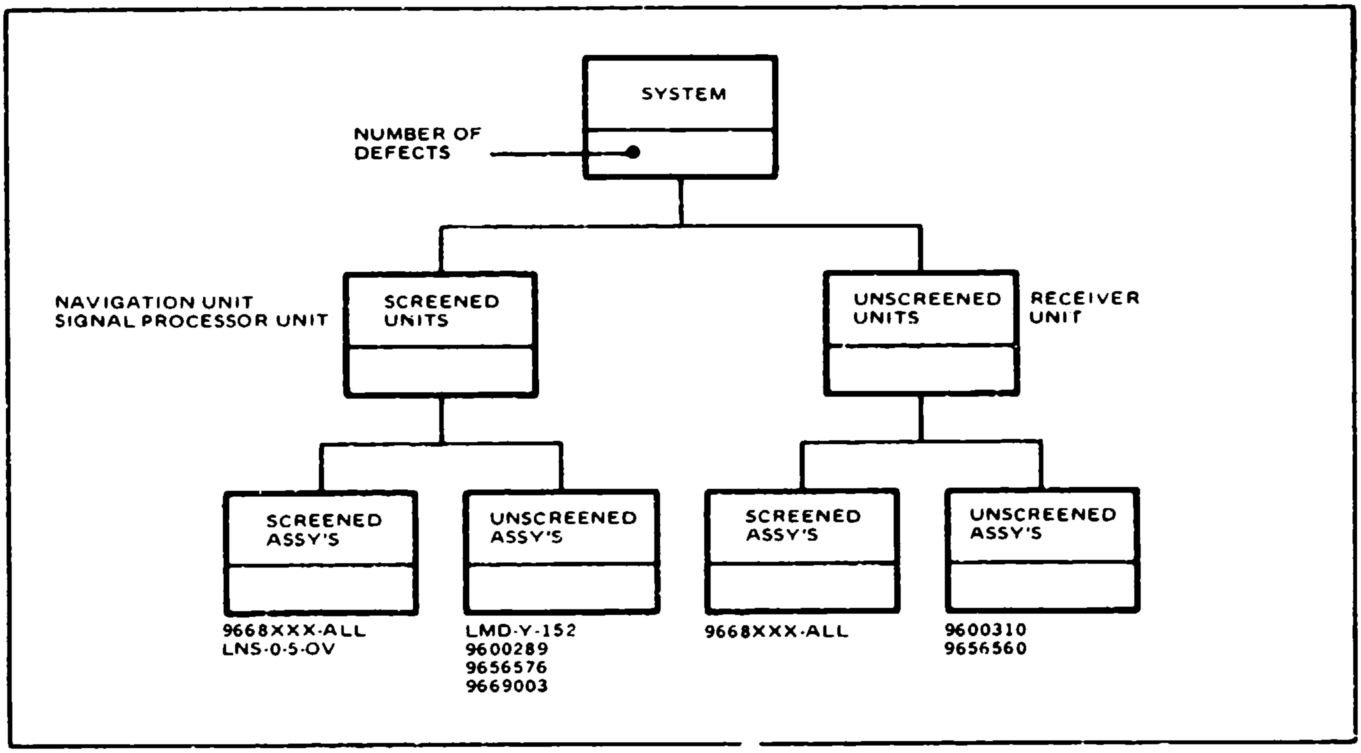

Figure 5. Identification of Equipment to Be Screened

TABLE XIV. APPROXIMATE VALUES OF DETECTION EFFICIENCY FOR VARIOUS TEST TYPES

Level Assembly	Test Type	Detection Efficiency
Assembly	Production Line GO-NO GO Test	0.85
	Production Line In-Circuit Test	0.90
	High Performance Automatic Tester	0.95
Unit	Performance Verification Test (PVT)	0.90
	Factory Checkout	0.95
	Final Acceptance Test	0.98
System	On-Line Performance Monitoring Test	0.90
	Factory Checkout Test	0.95
	Customer Final Acceptance Test	0.99

Instructions for use of the flow chart in Figure 4 are as follows:

Step 1. For each trial screening sequence, identify the units and assemblies that will be screened at their respective levels (See Figure 5).

Step 2. From the Defect Estimation Worksheets, or from the Unit Breakdown Charts, total the estimated number of defects in assemblies to be screened and enter in the block "ASS'Y DEF" for ASSEMBLY SCREEN 1.

Step 3. Similarly, total the estimated number of defects in assemblies that are not to be screened and enter in the block "ASS'Y DEF" for UNSCREENED ASSEMBLIES.

Step 4. Repeat steps 2 and 3 for Unit and System levels.

Step 5. Select candidate screens using the guidelines of paragraph 5.1.3. Determine screening strengths for selected screens from Tables XVII through XXI.

Step 6. Enter the Detection Efficiency (P_D) of the tests to be performed during and after screening as determined in paragraph 5.1.2.2. If a value for detection efficiency cannot be determined, the values in Table XIV shall be used.

Step 7. Compute test strengths by multiplying screening strengths by their respective detection efficiencies (SS x P_D) and enter (TS).

Step 8. Identify the unscreened assemblies that are installed in unscreened units and enter the total estimated number of defects for those assemblies in the UNSCREENED ASSEMBLIES block DEF REM 1 and in the block DEF ENT 1 of UNSCREENED UNITS. Enter the balance of estimated defects for unscreened assemblies in DEF REM 2.

Step 9. Determine which unscreened assemblies (DEF REM 2) will be installed in Units that will first enter UNIT SCREEN 1, UNIT SCREEN 2, or SYSTEM SCREEN. Enter the number of estimated defects into the corresponding DEF ENT 1 block(s).

Step 10. In the ASSEMBLY SCREEN 1 block, calculate the screening fallout, F, by multiplying the ASS'Y DEF by test strength, TS, and enter in block F. Subtract F from ASS'Y DEF and enter difference in DEF REM and in DEF ENT in ASSEMBLY SCREEN 2.

> NOTE: If a second assembly screen is not considered the test strength for ASSEMBLY SCREEN 2 is zero and the defects remaining (DEF REM) will be the same as the defects entering (DEF ENT).

Step 11. If TS $\neq$ 0 for ASSEMBLY SCREEN 2, calculate F by multiplying DEF ENT by TS. Subtract F from DEF ENT and enter in DEF REM.

Step 12. Determine which of the screened assemblies will be installed in Units that will enter UNIT SCREEN 1 and those that will be installed in unscreened units. Enter the number of estimated defects into the corresponding DEF ENT 2 block(s).

Step 13. In the UNIT SCREEN 1 block, calculate the total number of defects entering (DEF ENT 1 plus DEF ENT 2) and multiply by TS to determine F. Enter F. Subtract F from the sum of DEF ENT 1 and DEF ENT 2 and enter the difference in DEF REM and in the DEF ENT 2 block of UNIT SCREEN 2.

Step 14. In the UNIT SCREEN 2 block, repeat step 13. Enter the value in DEF REM in the block DEF ENT 2 of SYSTEM SCREEN if the System is to be screened or in the corresponding block in UNSCREENED SYSTEM if the system is not to be screened.

Step 15. In the UNSCREENED UNITS block, add the values in UNIT DEF, DEF ENT 1, and DEF ENT 2 and enter the sum in DEF REM.

Step 16. Determine which unscreened units will be screened as part of the system screen. Add the estimated defects for those units to the value in DEF ENT 1 of the SYSTEM SCREEN block. Enter the balance of estimated defects for unscreened units in DEF ENT 1 of the UNSCREENED SYSTEM block.

Step 17. In the SYSTEM SCREEN block, calculate F and subtract from the sum of DEF ENT 1 and DEF ENT 2. Enter the difference in DEF REM.

Step 18. In the UNSCREENED SYSTEM block, sum the values in SYS DEF, DEF ENT 1 and DEF ENT 2 and enter sum in DEF REM.

Step 19. Add the values in the DEF REM blocks of UNSCREENED SYSTEM and SYSTEM SCREEN blocks. The sum is D_{out}, an estimate of the number of defects remaining after completing the candidate screen. The value of D_{out} must be equal to or less than the number of defects remaining (D) to satisfy the specified yield requirement.

The above 19 steps complete the initial process of screen selection/placement and remaining defect calculation. The process shall be repeated with alternate or modified screens since more than one screening sequence may qualify as a candidate for subsequent cost tradeoff analysis (paragraph 5.1.4).

5.1.3 Selection and Placement of Screens

5.1.3.1 General. Stress screens are not all equally effective in transforming defects into detectable failures. The nature of defects varies with equipment type, manufacturer, and time. Screening effectiveness is achieved through proper application of screens, possible only through prior experience and experimentation.

Stress screens are intended primarily to precipitate part and workmanship defects but a natural by-product is the surfacing of design defects through extended exposure to environmental extremes. Vibration screens are considered to be effective for workmanship defects and thermal screens are considered to be effective for part defects. There are, however, classes of defects which are responsive to both vibration and thermal excitation. Table XV shows the distribution of defects by broad category for different stages of equipment maturity.

5.1.3.2 Initial Screen Selection and Placement. If the number of additional defects to be precipitated is relatively small, a single screen placed at the lowest level of assembly is most effective. If the number is large, placing screens at two or more levels of assembly, with stronger screens at lower levels, is effective. The types of screens selected shall be based on,

- prior knowledge of screening effectiveness
- available facilities
- design limits of equipment to be screened
- cost consideration
- published screening guidelines
- engineering judgment

Guidelines for initial screen selection and placement are provided in Table XVI. The stress screens for which screening strengths have been estimated are as follows:

(1) Temperature Cycle Screen (See Table XVII)
(2) Constant Temperature Screen (See Table XIX)
(3) Random Vibration Screen (See Table XX)
(4) Swept-Sine Vibration Screen (See Table XXI)

5.1.3.3 Selection of Screening Parameters. Screening parameters shall be selected to provide the highest screening strength consistent with the design limits of the equipment to be screened.

NOTE: Care shall be taken to assure that the design limits are not exceeded by the applied stresses.

TABLE XV. DEFECT DISTRIBUTION BY TYPE AND EQUIPMENT MATURITY

Maturity	Defect Distribution (percent)		
	Design	Manufacturing	Parts
Development	40-60	25-35	10-30
Early Production	20-40	30-50	20-40
Late Production	5-15	20-30	50-75

TABLE XVI. GUIDELINES FOR SCREEN SELECTION AND PLACEMENT

<table>
<tr><th rowspan="2">Level of Assembly</th><th colspan="4">Selection</th><th colspan="2">Placement</th></tr>
<tr><th>Temp Cycle</th><th>Const. Temp.</th><th>Rand Vib.</th><th>S.S. Vib.</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td rowspan="2">Assy</td><td>E[1]</td><td>M[2]</td><td>M[3]</td><td>N</td><td rowspan="2">• Cost per flaw precipitated is lowest (unpowered) screens
• Small size permits batch screening
• Low thermal mass allows high rates of temperature change
• Temperature range greater than operating range allowable for higher levels of assembly</td><td rowspan="2">• Test detection efficiency is relatively low
• Test equipment cost for powered screens is high</td></tr>
<tr><td colspan="4">E = Effective
M = Marginally Effective
N = Not Effective

Notes:
1. Particularly if power is applied and performance is monitored at temperature extremes.
2. Effective where assemblies contain complex devices (RAMs, microprocessors, hybrids)
3. Effectiveness highly dependent on assembly structure. Not effective for small, stiff PWAs.</td></tr>
<tr><td>Unit</td><td>E</td><td>M</td><td>E</td><td>M</td><td>• Relatively easy to power and monitor performance during screen
• Higher test detection efficiency than assembly level
• Assembly interconnections (e.g., wiring backplane) are screened</td><td>• Thermal mass precludes high rate of change, or requires costly facilities
• Cost per flaw significantly higher than assembly level
• Temperature range reduced from assembly level</td></tr>
</table>

TABLE XVI. GUIDELINES FOR SCREEN SELECTION AND PLACEMENT (Continued)

Level of Assembly	Selection				Placement	
	Temp Cycle	Const. Temp.	Rand Vib.	S.S. Vib.	Advantages	Disadvantages
System	E	M	E	M	• All potential sources of flaws are screened • Unit interoperability flaws detected • High test detection efficiency	• Difficult and costly to test at temperature extremes • Mass precludes use of effective vibration screens, or makes use costly • Cost per flaw is highest

For thermal screens, a thermal survey may be required to determine the thermal response characteristics of the equipment being screened to the applied thermal stresses. Similarly for vibration screens, a vibration survey may be required to determine the vibration response characteristics to the applied excitation. Parameters for each screen type are as follows:

a. Thermal Cycle Screens

(1) Temperature Range (R). This is the difference between the maximum and minimum applied external (chamber) temperatures ($T_{max} - T_{min}$). Temperatures are in °C.

NOTE: For internally cooled equipment (air or water) temperatures are those of the cooling medium.

(2) Temperature Rate of Change (DT). This is the average value of the temperature rate of change of the item being screened as it transitions between the temperature extremes. DT is in °C/minute.

$$DT = \left[\left(\frac{T_{max} - T_{min}}{t_1}\right) + \left(\frac{T_{max} - T_{min}}{t_2}\right)\right] \div 2 \qquad (6)$$

where

t_1 is the transition time from T_{min} to T_{max} (minutes)

t_2 is the transition time from T_{max} to T_{min} (minutes)

(3) Number of Cycles.

b. Constant Temperature Screens.

(1) Temperature Range (R). This is the absolute value of the difference between the temperature at which the equipment is being screened and 25°C.

$$R = |T-25| \quad (°C) \qquad (7)$$

where T is the external (chamber) temperature.

NOTE: For internally cooled equipment (air or water) T is the inlet temperature of the cooling medium.

(2) Duration. This is the period of time that the external temperature is applied to the equipment being screened, in hours.

c. Vibration Screens

(1) G-rms Level for Random Vibration. This is the rms value of the applied power (power spectral density) over the vibration frequency spectrum.

(2) G-level for Swept Sine Vibration. This is the constant acceleration applied to the equipment being screened throughout the frequency range above 40 Hz. The g-level below 40 Hz may be less.

(3) Duration. This is one period of time that the vibration excitation is applied to the equipment being screened in minutes. It is the per/axis time if excitation is repeated for multiple axes.

TABLE XVII. SCREENING STRENGTH, TEMPERATURE CYCLING SCREENS

Number of Cycles	DT =	Temperature Range (R) 20.	40.	60.	80.	100.	120.	140.	160.	180.
2.	5.	.1633	.2349	.2886	.3324	.3697	.4023	.4312	.4572	.4809
	10.	.2907	.4031	.4812	.5410	.5891	.6290	.6629	.6920	.7173
	15.	.3911	.5254	.6124	.6752	.7232	.7612	.7920	.8175	.8388
	20.	.4707	.6155	.7034	.7636	.8075	.8407	.8665	.8871	.9037
4.	5.	.2998	.4147	.4939	.5543	.6027	.6427	.6765	.7054	.7305
	10.	.4969	.6437	.7308	.7893	.8312	.8624	.8863	.9051	.9201
	15.	.6292	.7748	.8498	.8945	.9234	.9430	.9567	.9667	.9740
	20.	.7198	.8522	.9120	.9441	.9629	.9746	.9822	.9873	.9907
6.	5.	.4141	.5522	.6400	.7025	.7496	.7864	.8160	.8401	.8601
	10.	.6431	.7873	.8603	.9033	.9306	.9489	.9617	.9708	.9774
	15.	.7742	.8931	.9418	.9657	.9788	.9864	.9910	.9939	.9958
	20.	.8517	.9432	.9739	.9868	.9929	.9960	.9976	.9986	.9991
8.	5.	.5098	.6574	.7439	.8014	.8422	.8723	.8953	.9132	.9274
	10.	.7469	.8731	.9275	.9556	.9715	.9811	.9871	.9910	.9936
	15.	.8625	.9493	.9774	.9889	.9941	.9967	.9981	.9989	.9993
	20.	.9215	.9781	.9923	.9969	.9986	.9994	.9997	.9998	.9999
10.	5.	.5898	.7379	.8178	.8674	.9005	.9237	.9405	.9529	.9623
	10.	.8204	.9242	.9624	.9796	.9883	.9930	.9956	.9972	.9982
	15.	.9163	.9759	.9913	.9964	.9984	.9992	.9996	.9998	.9999
	20.	.9585	.9916	.9977	.9993	.9997	.9999	.9999	.9999	.9999
12.	5.	.6568	.7994	.8704	.9115	.9373	.9544	.9661	.9744	.9804
	10.	.8726	.9548	.9805	.9906	.9952	.9974	.9985	.9991	.9995
	15.	.9490	.9886	.9966	.9988	.9996	.9998	.9999	.9999	.9999
	20.	.9780	.9968	.9993	.9998	.9999	.9999	.9999	.9999	.9999

TABLE XVIII. $\bar{\lambda}_f$ VALUES FOR TEMPERATURE CYCLING SCREENS

Rate of Change	Temperature Range (R)								
	20.	40.	60.	80.	100.	120.	140.	160.	180.
DT =									
5.	0.0891	0.1339	0.1703	0.2020	0.2308	0.2573	0.2821	0.3055	0.3278
10.	0.1717	0.2580	0.3281	0.3893	0.4447	0.4958	0.5436	0.5888	0.6317
15.	0.2480	0.3726	0.4739	0.5623	0.6423	0.7161	0.7852	0.8504	0.9125
20.	0.3181	0.4779	0.6077	0.7212	0.8237	0.9184	1.0070	1.0906	1.1702

TABLE XIX. SCREENING STRENGTH, CONSTANT TEMPERATURE SCREENS

Time in Hours	Temperature Range (R)								
	0.	10.	20.	30.	40.	50.	60.	70.	80.
10.	0.0124	0.0677	0.0991	0.1240	0.1452	0.1639	0.1809	0.1964	0.2108
20.	0.0247	0.1308	0.1885	0.2326	0.2693	0.3010	0.3290	0.3542	0.3772
30.	0.0368	0.1896	0.2689	0.3278	0.3754	0.4156	0.4504	0.4810	0.5084
40.	0.0488	0.2445	0.3414	0.4112	0.4661	0.5114	0.5498	0.5830	0.6121
50.	0.0606	0.2956	0.4067	0.4842	0.5436	0.5915	0.6312	0.6649	0.6938
60.	0.0723	0.3433	0.4655	0.5481	0.6099	0.6584	0.6979	0.7307	0.7584
70.	0.0839	0.3877	0.5185	0.6042	0.6665	0.7144	0.7525	0.7836	0.8093
80.	0.0953	0.4292	0.5663	0.6533	0.7149	0.7612	0.7973	0.8261	0.8495
90.	0.1065	0.4678	0.6093	0.6963	0.7563	0.8004	0.8339	0.8602	0.8812
100.	0.1176	0.5038	0.6480	0.7339	0.7917	0.8331	0.8640	0.8877	0.9063
110.	0.1286	0.5374	0.6829	0.7669	0.8219	0.8605	0.8886	0.9097	0.9260
120.	0.1394	0.5687	0.7144	0.7958	0.8478	0.8833	0.9087	0.9275	0.9416
130.	0.1501	0.5979	0.7427	0.8211	0.8699	0.9025	0.9252	0.9417	0.9539
140.	0.1607	0.6251	0.7682	0.8433	0.8888	0.9184	0.9388	0.9532	0.9636
150.	0.1711	0.6505	0.7912	0.8628	0.9049	0.9318	0.9498	0.9624	0.9713
160.	0.1814	0.6742	0.8119	0.8798	0.9187	0.9430	0.9589	0.9697	0.9774
170.	0.1916	0.6962	0.8305	0.8947	0.9305	0.9523	0.9663	0.9757	0.9821
180.	0.2017	0.7168	0.8473	0.9077	0.9406	0.9602	0.9724	0.9805	0.9859
190.	0.2116	0.7360	0.8625	0.9192	0.9492	0.9667	0.9774	0.9843	0.9889
200.	0.2214	0.7538	0.8761	0.9292	0.9566	0.9721	0.9815	0.9874	0.9912
*f	0.0013	0.0070	0.0104	0.0132	0.0157	0.0179	0.0199	0.0219	0.0237

TABLE XX. SCREENING STRENGTH, RANDOM VIBRATION SCREENS

Duration (minutes)	G-RMS Level													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
5	0.007	0.023	0.045	0.072	0.104	0.140	0.178	0.218	0.260	0.303	0.346	0.389	0.431	0.473
10	0.014	0.045	0.088	0.140	0.198	0.260	0.324	0.389	0.452	0.514	0.572	0.627	0.677	0.723
15	0.021	0.067	0.129	0.202	0.282	0.363	0.444	0.522	0.595	0.661	0.720	0.772	0.816	0.854
20	0.028	0.088	0.168	0.260	0.356	0.452	0.543	0.626	0.700	0.764	0.817	0.861	0.896	0.923
25.	0.035	0.109	0.206	0.314	0.424	0.529	0.625	0.708	0.778	0.835	0.880	0.915	0.941	0.959
30.	0.041	0.129	0.241	0.363	0.484	0.595	0.691	0.772	0.836	0.885	0.922	0.948	0.966	0.979
35.	0.048	0.149	0.275	0.409	0.538	0.651	0.746	0.822	0.878	0.920	0.949	0.968	0.981	0.989
40.	0.055	0.168	0.308	0.452	0.586	0.700	0.791	0.860	0.910	0.944	0.966	0.981	0.989	0.994
45.	0.061	0.187	0.339	0.492	0.629	0.742	0.829	0.891	0.933	0.961	0.978	0.988	0.994	0.997
50.	0.068	0.205	0.369	0.529	0.668	0.778	0.859	0.915	0.951	0.973	0.986	0.993	0.996	0.998
55.	0.074	0.224	0.397	0.563	0.702	0.809	0.884	0.933	0.964	0.981	0.991	0.996	0.998	0.999
60.	0.081	0.241	0.424	0.595	0.734	0.836	0.905	0.948	0.973	0.987	0.994	0.997	0.999	1.000
$\bar{\lambda}_f$	0.084	0.276	0.552	0.903	1.322	1.806	2.351	2.954	3.613	4.327	5.092	5.905	6.776	7.692

TABLE XXI. SCREENING STRENGTH, SWEPT-SINE VIBRATION SCREENS

Duration (minutes)	G Level													
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
5.	0.0020	0.0036	0.0051	0.0066	0.0080	0.0093	0.0107	0.0120	0.0132	0.0145	0.0157	0.0169	0.0181	0.0193
10.	0.0040	0.0072	0.0103	0.0131	0.0159	0.0186	0.0212	0.0238	0.0263	0.0287	0.0312	0.0335	0.0359	0.0382
15.	0.0060	0.0108	0.0154	0.0196	0.0238	0.0278	0.0316	0.0354	0.0391	0.0428	0.0464	0.0499	0.0534	0.0568
20.	0.0080	0.0144	0.0204	0.0261	0.0316	0.0368	0.0420	0.0470	0.0519	0.0566	0.0614	0.0660	0.0705	0.0750
25.	0.0099	0.0180	0.0255	0.0325	0.0393	0.0458	0.0522	0.0584	0.0644	0.0703	0.0761	0.0818	0.0874	0.0929
30.	0.0119	0.0216	0.0305	0.0389	0.0470	0.0547	0.0623	0.0595	0.0768	0.0838	0.0906	0.0973	0.1039	0.1104
35.	0.0139	0.0251	0.0355	0.0452	0.0546	0.0636	0.0723	0.0807	0.0890	0.0970	0.1049	0.1126	0.1201	0.1275
40.	0.0159	0.0287	0.0404	0.0515	0.0621	0.0723	0.0822	0.0917	0.1010	0.1101	0.1189	0.1276	0.1361	0.1444
45.	0.0178	0.0322	0.0454	0.0578	0.0696	0.0810	0.0919	0.1026	0.1129	0.1230	0.1328	0.1424	0.1517	0.1609
50.	0.0198	0.0357	0.0503	0.0640	0.0770	0.0895	0.1016	0.1133	0.1246	0.1357	0.1464	0.1569	0.1671	0.1771
55.	0.0217	0.0392	0.0552	0.0701	0.0844	0.0980	[illegible]	0.1239	0.1362	0.1482	0.1598	0.1711	0.1822	0.1930
60.	0.0237	0.0427	0.0600	0.0763	0.0917	0.1065	0.1207	0.1344	0.1476	0.1605	0.1730	0.1852	0.1970	0.2085
$\bar{\lambda}_f$	0.0240	0.0436	0.0619	0.0793	0.0962	0.1126	0.1286	0.1443	0.1597	0.1749	0.1899	0.2048	0.2194	0.2339

5.1.4 <u>Cost-Effectiveness Tradeoff Analysis</u>. A cost analysis shall be performed for each candidate screen or screen sequence identified in paragraph 5.1.2. The worksheet shown in Figure 6 shall be used. Instructions for completing the worksheet follow:

a. <u>Fixed Screening Costs (lines 1, 7 and 13)</u>. These costs are one-time expenditures necessary for conduct of screening and typically include,

- Cost of screening facilities (prorated)
- Cost of test equipment and fixtures (prorated)
- Cost of screening program planning and preparation of procedures
- Cost of training

b. <u>Variable Screening Costs (lines 2, 8 and 14)</u>. These are recurring costs dependent on the volume of items to be screened and typically include,

- Cost of labor to conduct screening
- Cost of labor to record failures
- Cost of labor to conduct failure analysis
- Cost of labor for screening program management
- Cost of expendables (e.g., liquid nitrogen for chamber cooling)

These variable costs shall be calculated on a per system basis.

c. <u>Expected Fallout (lines 3, 9 and 15)</u>. These values are derived from Figure 4.

d. <u>Average Cost per Repair (lines 4, 10 and 16)</u>. These estimates are dependent on the types of equipment being screened and on the manufacturing facility repair capabilities. Where estimates are not available, default values are provided.

e. <u>Screening Repair Costs (lines 5, 11 and 17)</u>. Calculate as indicated on the worksheet.

f. <u>Screening Costs (lines 6, 12 and 18)</u>. Calculate as indicated on the worksheet. These costs are on a per system basis.

g. <u>Total Fixed Costs (line 19)</u>. Calculate as indicated on the worksheet.

COST ANALYSIS WORKSHEET		
System/Project	Prepared By	Date
I. ASSEMBLY SCREENING COST		Cost
1. Fixed Screening Cost		
2. Variable Screening Cost		
3. Expected Fallout (From Figure 4) (calculate on a system basis)		
4. Average Cost per Repair (if unknown, use $40)		
5. Screening Repair Cost (multiply line 3 by line 4)		
6. Assembly Level Screening Cost per system (add lines 2 and 5)		
II. UNIT SCREENING COST		
7. Fixed Screening Cost		
8. Variable Screening Cost		
9. Expected Fallout (From Figure 4) (calculate on a per-system basis)		
10. Average Cost per Repair (if unknown, use $375)		
11. Screening Repair Cost (multiply line 9 by line 10)		
12. Unit Level Screening Cost Per System (add lines 8 and 11)		
III. SYSTEM SCREENING COST		
13. Fixed Screening Cost		
14. Variable Screening Cost		
15. Expected Fallout From Figure 4, (calculate on a per system basis)		
16. Average Cost per Repair (if unknown, use $750)		
17. Screening Repair Cost (multiply line 15 by line 16)		
18. System Level Screening Cost per system (add lines 14 and 17)		
IV. TOTAL SCREENING COST		
19. Total Fixed Costs (add lines 1, 7 and 13)		
20. Screening Cost/System (add lines 6, 12 and 18)		
21. Number of Systems to be Screened		
22. System Screening Cost (multiply line 20 by line 21)		
23. Total Screening Cost (add lines 19 and 22)		
24. Expected Fallout per System (add lines 3, 9 and 15)		
25. Total Fallout (multiply line 24 by line 21)		
26. Cost per Defect Eliminated (divide line 23 by 25)		
27. Threshold Cost (if unknown, use $2000)		

Figure 6. Cost Analysis Worksheet

h. Screening Cost per System (line 20). This value is the total screening cost per system, excluding fixed costs.

i. Number of Systems to be Screened (line 21). This is an estimate of the quantity of systems expected to be subjected to stress screening.

j. Total Screening Cost (line 23). This is the total anticipated expenditure to conduct all stress screening.

k. Expected Fallout per System (line 24). Calculate as indicated on the worksheet.

l. Total Fallout (line 25). This is the total number of defects eliminated by stress screening all systems. Calculate as indicated on the worksheet.

m. Cost per Defect Eliminated (line 26). This is the average cost to eliminate a defect in the manufacturing process. Calculate as indicated on the worksheet.

n. Threshold Cost (line 27). This is the average cost per repair in the field and is provided by the PA. If a value is not available, use the default value on the worksheet.

Compare lines 26 and 27. If line 26 is less than line 27, the screening program is cost effective. All viable screening sequences identified in 5.1.2.4 shall be analyzed for cost-effectiveness and the sequence which has the lowest cost per defect eliminated (line 26) shall be selected.

5.1.5 Stress Screening Experimentation.

5.1.5.1 General. The stress screens/screening sequences selected on the basis of the initial planning steps of paragraphs 5.1.1 through 5.1.4 shall be implemented as early as possible during the development phase. In addition to eliminating defects and surfacing design weaknesses, a major objective of development phase stress screening shall be to verify the accuracy of the initial planning factors, including

- estimation of the number of defects
- effectiveness of stress screens
- selection and placement of screens
- types of defects present
- cost elements

Experimentation with modified stress screening parameters in an attempt to identify the most effective screens is encouraged.

5.1.5.2 Data Collection and Analysis. Stress screening fallout data shall be recorded and analyzed to determine the quantity and types of defects being precipitated. Sufficient analyses of failed parts shall be

made to identify potential latent defect as compared to chance failures, externally induced failures or unknown cause failures. This activity shall be integrated to the maximum extent possible with the normal failure data collection and analysis activities.

5.1.5.3 Screening Effectiveness Evaluation. Screening fallout data shall be analyzed in conjunction with failure data collected prior to and subsequent to screening to enable an evaluation of the estimates of defects present and screening effectiveness (screening strength values).

5.1.6 Stress Screening Plans.

5.1.6.1 Development Phase Plan. The contractor shall prepare a stress screening plan for the development phase that includes the following:

a. Identification of the equipment items to be screened.

b. Identification of potential stress screens to be applied.

c. Description of screening facilities available for use.

d. Description of the methods to be used for collection and analysis of screening fallout data.

e. Identification of the organizational elements that are responsible for planning and conduct of the stress screening.

The development phase plan shall be included as part of the Reliability Program Plan.

5.1.6.2 Production Phase Plan. The contractor shall prepare a stress screening plan for the production phase which shall include the following:

a. Detailed breakdown to the assembly level of the equipment to be screened as shown in Figures 1 and 2.

b. Defect Estimation Worksheets (Figure 3) for each item shown on the Unit Breakdown Charts.

c. Calculations to show the required screening strength (paragraph 5.1.2.3), or

d. Description of the candidate screening sequences (selection and placement of screens). Complete Figure 4 for each sequence.

e. Description of the cost analyses conducted to determine the most cost effective screen or screening sequences. (Complete Figure 6 for each candidate sequence.)

f. Description of the Failure-Free Test to be performed on each system to verify the yield. Show all calculations.

g. Description of the methods to be used for collection, analysis and reporting of screening fallout data.

h. Identification of the organizational elements responsible for planning and conduct of the stress screening.

5.2 <u>Production Phase ESS Monitoring and Control Requirements</u>.

5.2.1 <u>Monitoring, Evaluation and Control of Stress Screening</u>.

5.2.1.1 <u>Data Collection</u>. The contractor shall collect screening fallout data during the conduct of stress screening to allow an evaluation of screening effectiveness. The data collection shall be integrated to the maximum extent possible with the contractor's existing failure data collection and analysis systems. Data to be collected shall include:

a. Identification of the items screened (part and serial numbers).

b. The actual screening parameters used as determined by facility instrumentation and equipment recordings.

c. A detailed record of failures occurring during the screen or during tests conducted upon completion of the screen, including time of failure (relative to the start of the screen).

d. Fixed (one-time) screening costs for establishing and conducting the stress screening.

e. Variable (recurring) screening costs associated with the conduct of stress screening, including labor and time-dependent facilities costs related to stress screening conduct, repairs resulting from precipitated flaws, analysis of stress screening failures, collection and analysis of data, and other costs directly associated with stress screening.

5.2.1.2 <u>Data Classification and Analysis</u>.

5.2.1.2.1 <u>Classification of Failures</u>. All screening failures shall be analyzed to the extent necessary to permit classification into one of the following categories:

a. <u>Part Failure</u>. A primary failure or malfunction attributable to a basic weakness of the part.

b. <u>Design Failure</u>. A primary failure or malfunction attributable to a design deficiency. (Electrical or thermal overstress failures due to inadequate derating are design failure.)

c. Manufacturing Failure. A primary failure attributable to workmanship or lack of process control. Manufacturing failures shall be further classified as interconnection failures or other manufacturing failures.

d. Secondary Failure. A failure induced by occurrence of a primary failure.

e. Externally Induced Failure. A primary failure attributable to external influences such as prime power disturbances, facility or external equipment malfunctions and test personnel.

f. Software Failure. A malfunction attributable to a computer program error.

g. Unknown Cause Failure. An apparent primary failure resulting in a corrective maintenance action but the cause of which cannot be determined.

5.2.1.2.2 Analysis of Failure Data. Screening failure data shall be analyzed and corrective action taken, where possible, as follows:

a. Unknown Cause Failures. Special attention shall be given to unknown cause failures. Sufficient investigation shall be made to establish that an intermittent defect does not exist. Other unknown cause failures are, (1) incorrect diagnosis of symptoms, (2) transients/glitches, (3) off-line test detection efficiency and (4) plug-in contact high resistance.

b. Part and Interconnection Failures. All part and interconnection failures shall be assumed to be latent defects precipitated by screening and shall be analyzed as indicated in paragraph 5.2.1.3.

c. Design Failures. The cause of each design failure shall be determined and corrective action to preclude recurrence and correct the deficiency in delivered products shall be taken.

d. Software Failures. The software error that caused equipment malfunctions shall be identified and corrected.

e. Manufacturing Failures (other than interconnection failures). Investigation of each manufacturing failure shall be made to determine if the failure rate is within the expected rate based on workmanship standards and process capability. Corrective action is required where failure rates are above expected values.

f. Secondary and Induced Failures. Sufficient analysis of secondary and induced failures shall be made to determine necessary corrective actions to minimize recurrence.

5.2.1.3 Evaluation and Control. The quantity of part and interconnection failures assumed to be defects, shall be compared with the expected fallout as determined in the Defect Estimation Worksheets, Figure 3. Table XXII shall be used to determine if the observed fallout falls within a ninety percent probability interval.

The observed fallout may fall within, above or below the probability interval. Table XXIII provides recommended actions for all possible combinations of assembly, unit and system level observed results relative to the probabilty interval. The recommended actions relate to revising estimates for the expected number of incoming defects and the test strength of the selected screens. The revised estimates shall be consistent with the observed results. If the revised estimates result in an increase in remaining defects greater than the allowable number to meet the yield requirement (D), the screening regimen shall be appropriately modified.

5.2.1.3.1 Statistical Estimation of Screening Model Parameters. Use of the following alternate procedure for evaluation and control is recommended and shall also be considered.

Step 1. Based upon time-to-failure and the appropriate failure classification data obtained, per paragraphs 5.2.1.1 and 5.2.1.2, estimate the parameters of the Chance Defective Exponential (CDE) failure distribution model described in Appendix B using actual screening process results.

Step 2. Compare estimates of D_{in} (incoming defect levels) and $\bar{\lambda}_f$ (failure rate of defectives for specific screens), derived from step 1, with initial planning estimates. When repeated estimates of model/process parameters show consistent and significant differences from initial planning estimates, a reevaluation of the screening process shall be made.

Step 3. Repeat the tasks specified in paragraphs 5.1.2.4 and 5.1.4 using the estimates derived from the screening process rather than the initial planning estimates.

Step 4. Modify the screening regimen, as appropriate, using the results of Step 3, to assure achievement of screening program objectives.

5.2.2 Failure-Free Tests (FFT).

5.2.2.1 General. Each system offered for acceptance shall be subjected to a failure-free test immediately following or as an integral part of the system stress screen, if there is one, or as a part of the formal acceptance test of the system if a stress screen is not employed at the system level. The failure-free test shall be conducted under environmental stress conditions.

TABLE XXII. 90 PERCENT CONTROL PROBABILITY INTERVALS

Expected No. of Defects	Test Strength									
	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
5	4 1	5 1	5 1	5 1	5 2	5 2	5 2	5 3	5 3	5 4
6	5 1	5 1	5 2	6 2	6 2	6 3	6 3	6 4	6 [illegible]	6 5
7	6 1	6 2	6 2	6 2	7 3	7 3	7 4	7 4	7 5	7 6
8	6 2	7 2	7 3	7 3	8 3	8 4	8 4	8 5	8 6	8 6
9	7 2	7 3	8 3	8 3	8 4	9 5	9 5	9 6	9 6	9 7
10	8 2	8 3	8 3	9 4	9 5	10 5	10 6	10 7	10 7	10 8
11	8 3	9 3	9 4	10 4	10 5	10 6	11 6	11 7	11 8	11 9
12	9 3	9 4	10 4	10 5	11 6	11 6	12 7	12 8	12 9	12 10
13	9 4	10 4	11 5	11 6	12 6	12 7	13 8	13 9	13 10	13 11
14	10 4	11 5	11 5	12 6	12 7	13 8	13 9	14 10	14 11	14 12
15	11 4	11 5	12 6	13 7	13 7	14 8	14 9	15 10	15 11	15 13
16	11 5	12 6	13 6	13 7	14 8	15 9	15 10	16 11	16 12	16 14
17	12 5	13 6	13 7	14 8	15 9	16 10	16 11	17 12	17 13	17 14
18	12 6	13 6	14 7	15 8	16 9	16 10	17 11	18 13	18 14	18 15
19	13 6	14 7	15 8	16 9	16 10	17 11	18 12	18 13	19 15	19 16
20	14 6	15 7	16 8	16 9	17 11	18 12	19 13	19 14	20 16	20 17

5.2.2.2 <u>Determination of the Failure-Free Period</u>. The values of three parameters shall be determined

1. $N\bar{\lambda}_g$, the predicted failure rate of the system.

2. $\bar{\lambda}_f$, the average failure rate of defects under the stress screen. (Tables XVIII through XXI).

3. $\bar{\lambda}_f/N\bar{\lambda}_g$, the Failure Rate Ratio.

Using Table XXIV or XXV, enter the column corresponding to the calculated Failure Rate Ratio and find the row with the value of the specified yield and select the value of $\bar{\lambda}_f T$ (first column). Linear interpolation may be necessary. Calculate the required failure-free period. T, by dividing the $\bar{\lambda}_f T$ value by $\bar{\lambda}_f$. If the failure-free period is unreasonably or impractically long, proceed to Tables XXVI through XXXIII, in that order, until a reasonable value for the failure-free period is obtained.

5.2.2.3 <u>Pass-Fail Criteria</u>. The FFT shall be deemed to have passed if a contiguous period of T hours is observed without the occurrence of a failure. The contiguous period may include all or portions of the stress screen. The FFT shall be deemed to have failed if the pass criteria are not satisfied.

5.2.2.4 <u>Corrective Action</u>. If the FFT is failed, the contractor shall determine the cause of failure and propose corrective action to the PA.

TABLE XXIII. SUGGESTIONS FOR REVISING THE EXPECTED DEFECT PRECIPITATION ESTIMATES BASED ON OBSERVED RESULTS

Location of Observed Number of Defects Relative to Probability Interval			Alternative Recommended Actions					
			Assembly		Unit		Systems	
Assembly	Unit	System	ID	TS	ID	TS	ID	TS
Within	Within	Within	NC	NC	NC	NC	NC	NC
		Above	NC	NC	NC	NC	I	NC
		Below	NC	NC	NC	NC	D	NC
	Above	Within	NC	NC	I	NC	NC	NC
		Above	NC	NC	I	NC	NC	NC
		Below	NC	NC	I	I	NC	NC
	Below	Within	NC	NC	D	NC	NC	NC
		Above	NC	NC	NC	D	NC	NC
		Below	NC	NC	D	NC	NC	NC
Above	Within	Within	NC	I	NC	NC	NC	NC
		Above	NC	I	NC	NC	I	NC
		Below	NC	I	NC	NC	D	NC
	Above	Within	I	NC	NC	NC	NC	NC
		Above	I	NC	I	NC	NC	NC
		Below	I	NC	NC	I	NC	NC
	Below	Within	NC	I	NC	NC	NC	NC
		Above	I	NC	NC	D	NC	NC
		Below	NC	I	NC	NC	NC	NC
Below	Within	Within	D	NC	NC	NC	NC	NC
		Above	NC	D	NC	NC	NC	NC
		Below	D	NC	NC	NC	D	NC
	Above	Within	NC	D	NC	NC	NC	NC
		Above	NC	D	NC	NC	NC	NC
		Below	NC	D	NC	I	NC	NC
	Below	Within	D	NC	NC	NC	NC	NC
		Above	NC	D	NC	D	NC	NC
		Below	D	NC	D	NC	NC	NC

NC = No Change; I = Increase Est.; D = Decrease Est.
ID = Incoming Defects; TS = Strength

TABLE XXIV. 90 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

($\bar{\lambda}_f T$)	Failure Rate Ratio ($\bar{\lambda}f/N\bar{\lambda}_g$)												
	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.47	0.35	0.32	0.30	0.29	0.29	0.28	0.28	0.28	0.28	0.27	0.27	0.26
1.1	0.55	0.42	0.38	0.36	0.35	0.35	0.34	0.34	0.34	0.33	0.33	0.32	0.32
1.2	0.62	0.48	0.44	0.42	0.41	0.40	0.40	0.40	0.39	0.39	0.38	0.38	0.37
1.3	0.69	0.54	0.50	0.48	0.47	0.46	0.45	0.45	0.45	0.44	0.43	0.43	0.43
1.4	0.74	0.59	0.55	0.53	0.52	0.51	0.50	0.50	0.50	0.49	0.48	0.48	0.47
1.5	0.79	0.64	0.60	0.57	0.56	0.55	0.55	0.54	0.54	0.54	0.53	0.52	0.52
1.6	0.84	0.68	0.64	0.62	0.61	0.60	0.59	0.59	0.58	0.58	0.57	0.56	0.56
1.7	0.87	0.72	0.68	0.66	0.64	0.64	0.63	0.63	0.62	0.62	0.61	0.60	0.60
1.8	0.91	0.76	0.71	0.69	0.68	0.67	0.67	0.66	0.66	0.66	0.65	0.64	0.64
1.9	0.93	0.79	0.75	0.73	0.71	0.71	0.70	0.70	0.69	0.69	0.68	0.67	0.67
2.0	0.95	0.82	0.77	0.75	0.74	0.73	0.73	0.73	0.72	0.72	0.71	0.70	0.70
2.2	0.99	0.86	0.82	0.80	0.79	0.79	0.78	0.78	0.77	0.77	0.76	0.76	0.75
2.4	1.00	0.90	0.86	0.84	0.83	0.83	0.82	0.82	0.82	0.81	0.80	0.80	0.80
2.6	1.00	0.92	0.89	0.88	0.87	0.86	0.86	0.85	0.85	0.85	0.84	0.84	0.83
2.8	1.00	0.94	0.92	0.90	0.89	0.89	0.88	0.88	0.88	0.88	0.87	0.87	0.86
3.0	1.00	0.96	0.93	0.92	0.91	0.91	0.91	0.90	0.90	0.90	0.89	0.89	0.89
3.5	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.94	0.94	0.94	0.93	0.93
4.0	1.00	0.99	0.98	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.96
5.0	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE XXV. 90 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio, $(\bar{\lambda}_f/N\bar{\lambda}_g)$									
$(\bar{\lambda}_f T)$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.3	1.00	0.10	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00
0.4	1.00	0.54	0.14	0.07	0.05	0.04	0.03	0.03	0.02	0.02
0.5	1.00	1.00	0.38	0.20	0.13	0.10	0.09	0.08	0.07	0.06
0.6	1.00	1.00	0.69	0.38	0.26	0.21	0.17	0.15	0.14	0.13
0.7	1.00	1.00	1.00	0.58	0.41	0.33	0.28	0.24	0.22	0.21
0.8	1.00	1.00	1.00	0.78	0.56	0.45	0.39	0.35	0.32	0.29
0.9	1.00	1.00	1.00	0.96	0.71	0.58	0.50	0.45	0.41	0.38
1.0	1.00	1.00	1.00	1.00	0.84	0.69	0.60	0.54	0.50	0.47
1.1	1.00	1.00	1.00	1.00	0.95	0.79	0.69	0.63	0.58	0.55
1.2	1.00	1.00	1.00	1.00	1.00	0.88	0.78	0.71	0.66	0.62
1.3	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.78	0.73	0.69
1.4	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.83	0.78	0.74
1.5	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.88	0.83	0.79
1.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.88	0.84
1.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.91	0.87
1.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.94	0.91
1.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.93
2.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.95

TABLE XXVI. 80 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

	Failure Rate Ratio ($\bar{\lambda}f/N\bar{\lambda}_g$)												
($\bar{\lambda}_f T$)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.70	0.52	0.48	0.45	0.44	0.43	0.43	0.42	0.42	0.42	0.40	0.40	0.40
1.1	0.78	0.59	0.54	0.51	0.50	0.49	0.48	0.48	0.48	0.47	0.46	0.45	0.45
1.2	0.84	0.65	0.59	0.57	0.55	0.54	0.54	0.53	0.53	0.53	0.51	0.51	0.50
1.3	0.89	0.70	0.64	0.62	0.60	0.59	0.59	0.58	0.58	0.57	0.56	0.55	0.55
1.4	0.83	0.74	0.69	0.66	0.65	0.63	0.63	0.63	0.62	0.62	0.60	0.60	0.60
1.5	0.97	0.78	0.73	0.70	0.69	0.68	0.67	0.66	0.66	0.66	0.64	0.64	0.63
1.6	1.00	0.81	0.76	0.74	0.72	0.71	0.71	0.70	0.70	0.69	0.68	0.67	0.67
1.7	1.00	0.84	0.79	0.77	0.75	0.74	0.74	0.73	0.73	0.72	0.71	0.70	0.70
1.8	1.00	0.87	0.82	0.79	0.78	0.77	0.77	0.76	0.76	0.75	0.74	0.73	0.73
1.9	1.00	0.89	0.84	0.82	0.81	0.80	0.79	0.79	0.78	0.78	0.77	0.76	0.76
2.0	1.00	0.91	0.86	0.84	0.83	0.82	0.81	0.81	0.80	0.80	0.79	0.78	0.78
2.2	1.00	0.94	0.90	0.88	0.86	0.86	0.85	0.85	0.84	0.84	0.83	0.82	0.82
2.4	1.00	0.96	0.92	0.90	0.89	0.89	0.88	0.88	0.87	0.87	0.86	0.86	0.86
2.6	1.00	0.98	0.94	0.93	0.92	0.91	0.91	0.90	0.90	0.90	0.89	0.88	0.88
2.8	1.00	0.99	0.96	0.94	0.93	0.93	0.92	0.92	0.92	0.92	0.91	0.91	0.90
3.0	1.00	0.99	0.97	0.96	0.95	0.94	0.94	0.94	0.94	0.93	0.93	0.92	0.92
3.5	1.00	1.00	0.99	0.98	0.97	0.97	0.97	0.96	0.96	0.96	0.96	0.95	0.95
4.0	1.00	1.00	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97
5.0	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE XXVII. 80 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio, $(\bar{\lambda}_f/N\bar{\lambda}_g)$									
$(\bar{\lambda}_f T)$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	0.06	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
0.3	.100	0.73	0.18	0.09	0.06	0.04	0.03	0.03	0.03	0.02
0.4	1.00	1.00	0.57	0.29	0.19	0.15	0.12	0.10	0.09	0.09
0.5	1.00	1.00	1.00	0.57	0.39	0.30	0.25	0.22	0.20	0.18
0.6	1.00	1.00	1.00	0.88	0.61	0.48	0.40	0.35	0.32	0.29
0.7	1.00	1.00	1.00	1.00	0.81	0.65	0.55	0.48	0.44	0.41
0.8	1.00	1.00	1.00	1.00	0.99	0.80	0.68	0.61	0.56	0.52
0.9	1.00	1.00	1.00	1.00	1.00	0.93	0.80	0.72	0.66	0.62
1.0	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.81	0.75	0.70
1.1	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.89	0.82	0.78
1.2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.89	0.84
1.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.89
1.4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.93
1.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97

TABLE XXVIII. 70 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

	Failure Rate Ratio ($\bar{\lambda}_f/N\bar{\lambda}_g$)											
($\bar{\lambda}_f T$)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	0.89	0.66	0.60	0.57	0.56	0.55	0.54	0.53	0.53	0.53	0.51	0.50	0.50
1.1	0.95	0.72	0.66	0.63	0.61	0.60	0.59	0.59	0.58	0.58	0.56	0.56	0.55
1.2	1.00	0.77	0.71	0.68	0.66	0.65	0.64	0.63	0.63	0.63	0.61	0.60	0.60
1.3	1.00	0.81	0.75	0.72	0.70	0.69	0.68	0.68	0.67	0.67	0.65	0.64	0.64
1.4	1.00	0.85	0.79	0.76	0.74	0.73	0.72	0.71	0.71	0.71	0.69	0.68	0.68
1.5	1.00	0.88	0.82	0.79	0.77	0.76	0.75	0.75	0.74	0.74	0.72	0.72	0.71
1.6	1.00	0.90	0.84	0.82	0.80	0.79	0.78	0.78	0.77	0.77	0.75	0.74	0.74
1.7	1.00	0.92	0.87	0.84	0.82	0.81	0.81	0.80	0.80	0.79	0.78	0.77	0.77
1.8	1.00	0.94	0.89	0.86	0.85	0.84	0.83	0.82	0.82	0.82	0.80	0.79	0.79
1.9	1.00	0.96	0.90	0.88	0.87	0.86	0.85	0.84	0.84	0.84	0.82	0.82	0.81
2.0	1.00	0.97	0.92	0.90	0.88	0.87	0.87	0.86	0.86	0.85	0.84	0.83	0.83
2.2	1.00	0.99	0.94	0.92	0.91	0.90	0.90	0.89	0.89	0.88	0.87	0.87	0.86
2.4	1.00	1.00	0.96	0.94	0.93	0.92	0.92	0.91	0.91	0.91	0.90	0.89	0.89
2.6	1.00	1.00	0.97	0.96	0.95	0.94	0.94	0.93	0.93	0.93	0.92	0.91	0.91
2.8	1.00	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.94	0.93	0.93	0.93
3.0	1.00	1.00	0.99	0.98	0.97	0.96	0.96	0.96	0.96	0.95	0.95	0.94	0.94
3.5	1.00	1.00	1.00	0.99	0.98	0.98	0.98	0.98	0.97	0.97	0.97	0.97	0.96
4.0	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98	0.98
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE XXIX. 70 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio, $(\bar{\lambda}_f/N\bar{\lambda}_g)$									
$(\bar{\lambda}_f T)$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	0.40	0.09	0.04	0.03	0.02	0.02	0.01	0.01	0.01
0.3	1.00	1.00	0.56	0.27	0.18	0.13	0.11	0.09	0.08	0.08
0.4	1.00	1.00	1.00	0.66	0.44	0.34	0.28	0.24	0.21	0.20
0.5	1.00	1.00	1.00	1.00	0.73	0.56	0.47	0.41	0.37	0.34
0.6	1.00	1.00	1.00	1.00	1.00	0.78	0.66	0.58	0.52	0.48
0.7	1.00	1.00	1.00	1.00	1.00	0.96	0.82	0.72	0.66	0.61
0.8	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.77	0.72
0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.87	0.81
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.89
1.1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95

TABLE XXX. 60 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

	Failure Rate Ratio ($\bar{\lambda}_f/N\bar{\lambda}_g$)												
($\bar{\lambda}_f T$)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	1.00	0.78	0.71	0.68	0.66	0.65	0.64	0.63	0.63	0.62	0.60	0.60	0.59
1.1	1.00	0.83	0.76	0.73	0.71	0.69	0.68	0.68	0.67	0.67	0.65	0.64	0.64
1.2	1.00	0.87	0.80	0.77	0.75	0.73	0.73	0.72	0.71	0.71	0.69	0.68	0.68
1.3	1.00	0.91	0.83	0.80	0.78	0.77	0.76	0.75	0.75	0.74	0.73	0.72	0.72
1.4	1.00	0.93	0.86	0.83	0.81	0.80	0.79	0.78	0.78	0.78	0.76	0.75	0.75
1.5	1.00	0.95	0.89	0.86	0.84	0.83	0.82	0.81	0.81	0.80	0.79	0.78	0.77
1.6	1.00	0.97	0.91	0.88	0.86	0.85	0.84	0.83	0.83	0.83	0.81	0.80	0.80
1.7	1.00	0.99	0.92	0.90	0.88	0.87	0.86	0.85	0.85	0.85	0.83	0.82	0.82
1.8	1.00	1.00	0.94	0.91	0.90	0.89	0.88	0.87	0.87	0.86	0.85	0.84	0.84
1.9	1.00	1.00	0.95	0.93	0.91	0.90	0.89	0.89	0.88	0.88	0.87	0.86	0.86
2.0	1.00	1.00	0.96	0.94	0.92	0.91	0.91	0.90	0.90	0.89	0.88	0.87	0.87
2.2	1.00	1.00	0.98	0.96	0.94	0.93	0.93	0.92	0.92	0.92	0.90	0.90	0.90
2.4	1.00	1.00	0.99	0.97	0.96	0.95	0.94	0.94	0.94	0.93	0.92	0.92	0.92
2.6	1.00	1.00	1.00	0.98	0.97	0.96	0.96	0.95	0.95	0.95	0.94	0.93	0.93
2.8	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.95	0.95	0.95
3.0	1.00	1.00	1.00	0.99	0.98	0.98	0.97	0.97	0.97	0.97	0.96	0.96	0.96
3.5	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97
4.0	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.98	0.98
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE XXXI. 60 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

	Failure Rate Ratio, $(\bar{\lambda}_f/N\bar{\lambda}_g)$									
$(\bar{\lambda}_f T)$	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	1.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.2	1.00	1.00	0.32	0.15	0.10	0.07	0.06	0.05	0.04	0.04
0.3	1.00	1.00	1.00	0.62	0.40	0.30	0.25	0.21	0.19	0.17
0.4	1.00	1.00	1.00	1.00	0.79	0.60	0.50	0.43	0.38	0.35
0.5	1.00	1.00	1.00	1.00	1.00	0.88	0.73	0.64	0.57	0.53
0.6	1.00	1.00	1.00	1.00	1.00	1.00	0.93	0.82	0.74	0.68
0.7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	0.87	0.81
0.8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.91
0.9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99

TABLE XXXII. 50 PERCENT LOWER CONFIDENCE BOUND ON YIELD (1-60)

	Failure Rate Ratio ($\bar{\lambda}_f/N\bar{\lambda}_g$)												
($\bar{\lambda}_f T$)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	20.00	40.00	60.00 or More
1.0	1.00	0.89	0.81	0.77	0.75	0.74	0.73	0.72	0.71	0.71	0.69	0.68	0.67
1.1	1.00	0.93	0.85	0.81	0.79	0.78	0.77	0.76	0.75	0.75	0.73	0.72	0.71
1.2	1.00	0.96	0.88	0.84	0.82	0.81	0.80	0.79	0.79	0.78	0.76	0.75	0.75
1.3	1.00	0.98	0.91	0.87	0.85	0.84	0.83	0.82	0.81	0.81	0.79	0.78	0.78
1.4	1.00	1.00	0.93	0.89	0.87	0.86	0.85	0.84	0.84	0.83	0.82	0.81	0.80
1.5	1.00	1.00	0.95	0.91	0.89	0.88	0.87	0.86	0.86	0.86	0.84	0.83	0.83
1.6	1.00	1.00	0.96	0.93	0.91	0.90	0.89	0.88	0.88	0.87	0.86	0.85	0.84
1.7	1.00	1.00	0.97	0.94	0.92	0.91	0.90	0.90	0.89	0.89	0.87	0.86	0.86
1.8	1.00	1.00	0.98	0.95	0.94	0.93	0.92	0.91	0.91	0.90	0.89	0.88	0.88
1.9	1.00	1.00	0.99	0.96	0.95	0.94	0.93	0.92	0.92	0.92	0.90	0.89	0.89
2.0	1.00	1.00	1.00	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.91	0.90	0.90
2.2	1.00	1.00	1.00	0.98	0.97	0.96	0.95	0.95	0.95	0.94	0.93	0.92	0.92
2.4	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.96	0.96	0.96	0.94	0.94	0.94
2.6	1.00	1.00	1.00	1.00	0.99	0.98	0.97	0.97	0.97	0.97	0.96	0.95	0.95
2.8	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.96	0.96	0.96
3.0	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97
3.5	1.00	1.00	1.00	1.00	1.00	1.00	0.99	.099	0.99	0.99	0.98	0.98	0.98
4.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99
5.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE XXXIII. 50 PERCENT LOWER CONFIDENCE BOUND ON YIELD (0.1-1.0)

$(\bar{\lambda}_f T)$	Failure Rate Ratio, $(\bar{\lambda}_f/N\bar{\lambda}_g)$									
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
0.1	1.00	0.16	0.03	0.01	0.01	0.01	0.01	0.00	0.00	0.00
0.2	1.00	1.00	0.89	0.42	0.27	0.20	0.16	0.14	0.12	0.11
0.3	1.00	1.00	1.00	1.00	0.77	0.58	0.47	0.40	0.36	0.33
0.4	1.00	1.00	1.00	1.00	1.00	0.95	0.78	0.68	0.60	0.55
0.5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.81	0.74
0.6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.89

CUSTODIANS

Army - CR
Navy - EC

REVIEW ACTIVITIES

Army -
Navy -
Air Force -

USER ACTIVITIES

Army -
Navy -
Air Force

PREPARING ACTIVITY

AF-17
Proj # RELI-0031

APPENDIX A

APPLICATION GUIDELINES

10.0 SCOPE

10.1 This appendix contains guidelines for application of this military standard and identifies requirements for information to be supplied by the PA.

20.0 APPLICABLE DOCUMENTS

20.1 None

30.0 STRESS SCREENING APPLICATION

30.1 The primary objective of ESS is to precipitate latent part and workmanship defects during manufacture, eliminating the major cause of early field failures. Stress screening is particularly effective when strong screens (random vibration and temperature cycling) are applied to complex hardware in early production. The number of part defects present in equipment increases with hardware complexity (part count). Workmanship defects are common in early production due to engineering-to-production transition difficulties, initial planning errors, documentation errors and worker learning curves. The incidence of part defects is reduced significantly when screened parts are used, rescreening is employed at receiving inspection, an effective parts control program is in place and the parts handling process (including disciplined ESD control) in the production facility is under control. Lacking one or more of the above will result in a level of part defects commensurate with the lack of control. Workmanship defects are rapidly reduced as production matures provided that the designs are stable (few engineering changes), designs are producible, modern production methods are used, production processes are under control (preferably in statistical quality control) and an effective defect data collection, analysis and feedback program is in place. As with part defects, a level of workmanship defects will remain if one or more of the controls are not applied.

Under ideal conditions, ESS is employed in early production until the causes of all correctable defects are eliminated and part and workmanship controls are in place and operating effectively at which time ESS is no longer necessary. This ideal condition can arise with high volume, long term production runs of stable, producible designs in a dedicated production facility. If such ideal condition cannot be anticipated, continuous stress screening may be required.

The data base required for application of quantitative stress screening techniques is largely undeveloped at present. A methodology for estimating the number of defects expected to be present in equipment cannot be uniformly applied to all types of equipment and the effectiveness of stress

screens, in quantitative terms, is still uncertain. Therefore, it is imperative that stress screening be employed during the development phase so that experimentation can be done with various screens and screening parameters to determine which screens are truly effective and fallout data can be analyzed to determine the nature and magnitude of defects present. The development phase stress screening provides a sound basis for planning a production phase stress screening program. Stress screening has proven, in the past, to be an effective find-and-fix program, surfacing latent design deficiencies, an added benefit of application of stress screening in both development and early production.

40.0 COST EFFECTIVENESS OF STRESS SCREENING

40.1 For repairable systems, it is economical to do stress screening if the average cost per defect eliminated is less than the cost of field repair caused by a failure. The average cost per defect eliminated (C_D) is,

$$C_D = \frac{\text{Total Screening Program Costs}}{\text{Number of Defects Eliminated}}$$

The cost per field repair is uncertain, with estimates ranging from about $1,000 to over $15,000, depending on estimating methods used.

50.0 SPECIFYING YIELD

50.1 The contractor is required to perform a cost effectiveness tradeoff analysis (paragraph 5.1.4), determining first whether a cost effective stress screening program can be designed to achieve the required yield. The basis of this determination is the <u>Cost Threshold, specified by the PA</u>, which is the cost per field repair.

The PA is required to specify the minimum yield requirement in the procurement documents. It is essential that the yield value specified be consistent with the equipment being procured to assure maximum probability of success of stress screening. Therefore, the following guidelines are provided for specifying the minimum value for yield.

$$\text{Yield} = 1 - \frac{1}{\left[1 + \left(\frac{\theta_0}{493}\right)^{1.42}\right]}$$

Where θ_0 is the specified, or upper test, mean-time-between-failure (MTBF) value. Values of minimum required yield are shown in Table A.1.

60.0 FAILURE-FREE TESTS (FFT)

60.1 The FFT designed for this standard verify yield to confidence levels of .50, .60, .70, .80 and .90. The contractor is required to select a failure-free period corresponding to the .90 confidence that the yield is not less than the specified yield). However, depending on the stress screen selected for the FFT, the failure-free period may be unreasonably or

impractically long and he contractor may select a stronger screen or propose an FFT with a lower confidence level. Judgement is required by the PA to determine what is reasonable and practical.

TABLE A.1. YIELD VALUES CORRESPONDING TO SPECIFIED MTBF

MTBF	YIELD	MTBF	YIELD	MTBF	YIELD
100	.09	1,850	.87	3,600	.94
150	.16	1,900	.87		
200	.22	1,950	.88	3,800	.95
250	.28	2,000	.88		
300	.33	2,050	.88	4,000	.95
350	.38	2,100	.89		
400	.43	2,150	.89	4,200	.95
450	.48	2,200	.89	4,400	.96
500	.51	2,250	.90	4,600	.96
550	.54	2,300	.90	4,800	.96
600	.57	2,350	.90	5,000	.96
650	.60	2,400	.90	6,000	.97
700	.62	2,450	.91	7,000	.98
750	.64	2,500	.91	8,000	.98
800	.67			9,000	.98
850	.68	2,600	.91	10,000	.99
900	.70			20,000	.995
950	.72	2,700	.92	30,000	.997
1,000	.73			40,000	.998
1,050	.75	2,800	.92	50,000	.9985
1,100	.76			60,000	.999
1,150	.77	2,900	.93	70,000	.9991
1,200	.78			80,000	.9993
1,250	.79	3,000	.93	90,000	.9994
1,300	.80			100,000	.9995
1,350	.81	3,100	.93		
1,400	.81				
1,450	.82	3,200	.93		
1,500	.83				
1,550	.84	3,300	.94		
1,600	.84				
1,650	.85	3,400	.94		
1,700	.85				
1,750	.86	3,500	.94		
1,800	.86				

APPENDIX B

CHANCE DEFECTIVE EXPONENTIAL (CDE) MODEL

10.0 SCOPE

10.1 This appendix contains a description of the Chance Defective Exponential failure distribution model. The CDE model is applicable to the screening process and provides a framework for the quantitative procedures contained in the standard.

20.0 APPLICABLE DOCUMENTS

20.1 None

30.0 MODEL DESCRIPTION

30.1 The CDE model is based upon the assumption that the population of parts within an equipment is comprised of two sub-populations, viz., a main subpopulation of "good" or nondefective parts and a subpopulation of defectives. The defectives contain major flaws which degrade with time and stress and are manifested as early life failures. The term "part" refers to any identifiable item within the equipment which can be removed or repaired and thus could be a discrete semiconductor, IC, connector or solder joint.

The reliability function for the CDE model is:

$$R(t) = \exp\left[-(N-D)\bar{\lambda}_g\right] - D(1-e^{\bar{\lambda}_f t})$$

where:

- N = total number of parts in a given equipment ("goods" and defectives)
- D = average number of defectives per equipment
- $\bar{\lambda}_g$ = average failure rate of the "good" parts. The failure distribution of the "good" parts in an equipment is exponential with constant failure rate $(N-D)\lambda_g$.
- $\bar{\lambda}_f$ = average failure rate of a defective part. The failure distribution of defectives is exponential with constant failure rate λ_f. The failure rate $\bar{\lambda}_f$ is a function of the stress environment to which the equipment is exposed.

The hazard or instantaneous failure rate is given by:

$$\lambda(t) = (N-D)\,\bar{\lambda}_g + D\bar{\lambda}_f e^{-\bar{\lambda}_f t}$$

and the expected number of failures in time t is given by:

$$E(t) = (N-D)\,\bar{\lambda}_g\, t + D\,(1 - e^{-\bar{\lambda}_f t}).$$